NITRATE IN DRINKING WATER
REPORT TO THE LEGISLATURE

REPORT NO. 88-11WQ
DIVISION OF WATER QUALITY

STATE WATER RESOURCES CONTROL BOARD

OCTOBER 1988

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Edward C. Anton
Jeffrey L. Barnickol
Dean R. Schnaible

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EXECUTIVE SUMMARY

The 1987 Budget Act directed the State Water Resources Control Board to prepare this report on nitrate contamination of drinking water in the State of California. The report documents that nitrate contamination poses a quantitative threat to the supply of drinking water (primarily ground water resources) that is equal to or exceeds that of the toxics issues which have received so much public attention. For example, the Metropolitan Water District of southern California estimates it is losing four percent of its drinking water supply annually to nitrate and total dissolved solids (primarily nitrate). Comparatively, it further reports that, to date, less than one-half percent of its drinking water supply has been lost because of toxic organic contamination.

Another example is the Salinas Valley where local officials estimate that by the year 2000 the ground water contained in most of the unconfined aquifers of the Salinas Valley will exceed the drinking water standard for nitrate.

The first part of this report identifies the nitrate situation in California by geographic area. It further identifies the actual or probable sources of this nitrate contamination of drinking water, and describes the health, environmental, and economic consequences of nitrate contamination. The significant sources of nitrate problems identified by this research include fertilizer use (mostly by agriculture), large concentrations of confined animals, individual waste disposal systems, and to a minor extent, municipal wastewater treatment. Natural areas of high nitrate are of local but minor importance.

The second part of this report addresses the sources of data that are available regarding nitrate in drinking water and the deficiencies in this data. Data sources used in the compilation of this information included State and Federal agencies, county agencies (principally the environmental health departments), public and private water suppliers, and pertinent literature that was immediately available. The ease with which nitrate data can be obtained, and the adequacy of that data are reviewed, and the shortcomings of th data are pointed out. Chief among these shortcomings are t lack of knowledge or exchange of existing nitrate data and the inadequacy of sampling systems directed toward nitrate problem identification.

The third part of this report contains workplans. The first is to develop remedies for the deficiencies found in the data. The second is a workplan to develop solutions to the current nitrate problems in drinking water supplies, and the third is a workplan to develop approaches or actions that will eliminate or reduce the ongoing threat that nitrate poses to drinking water supplies.

The data deficiencies workplan prescribes actions that would more comprehensively assess the extent of nitrate problems in California and that would develop solutions to the data exchange and inadequate sampling systems.

The problem solution workplans prescribe an evaluation of possible actions to address current and future nitrate problems. Protection, remedial action, and cleanup possibilities would be considered in both volunteer and regulatory context. Investigation of possible incentives to perform would also be included. These evaluations would focus on the primary sources of nitrate problems, fertilizer, confined animals, and individual waste disposal systems.

Acknowledgements

This report has been prepared by the State Water Resources Control Board with the cooperation and data furnished by the following major contributors:

State Department of Food and Agriculture
State Department of Health
State Department of Water Resources
Regional Water Quality Control Boards
The County Environmental Health Directors
The Metropolitan Water District of Southern California
Orange County Water District
Kern County Water Agency
Monterey County Flood Control & Water Conservation District
United States Geological Survey

CHAPTER I
INTRODUCTION - AUTHORITY FOR REPORT

The 1987 Budget Act forwarded to the Governor by the Legislature included a request that the State Water Resources Control Board (State Board) prepare a report on nitrate contamination of drinking water.

The supplemental language (Item 3940-001-001 of the Supplemental Report of the 1987 Budget Act) specified that the report be submitted to the Legislature by October 1, 1988, that the Departments of Health Services and Food and Agriculture assist the State Board with the report, and that the report include, but not be limited to:

A. An identification of the problems associated with elevated nitrate levels in drinking water supplies,
B. An identification of the sources of these elevated levels in drinking water supplies,
C. To the extent that information exists, an evaluation of the impact of different sources of nitrate, as they occur both naturally and as a result of human activity, in regards to the contamination of State drinking water supplies,
D. In the event that existing information is not adequate to allow formulation of general observations, then a proposal identifying what steps should be taken to obtain more detailed information shall be developed, and
E. A report on regulatory actions which can be taken by the public sector, and voluntary actions which can be taken by the private sector, to negate or reduce the problems associated with elevated nitrate levels in drinking water supplies.

The State Board has investigated the extent of nitrate problems in drinking water sources and the probable sources of those problems based on current information. The adequacy of the current information was assessed, and workplans for approaches to solve deficiencies in the current information base and to solve the actual nitrate problems in drinking water were developed. The results of this effort are presented in the attached report.

CHAPTER II
BACKGROUND ON NITROGEN

A. Nitrate and Nitrogen

There are four major reservoirs of Nitrogen which both man and nature access to create nitrate directly and indirectly. The atmosphere is one, the ocean another, terrestrial soils are a third, and the underlying geology is the fourth. These reservoirs, while important conceptually, are not problematic in and of themselves, in fact, life evolved in their presence and is dependent on them. On a planetary scale, nitrates in drinking water supplies represent only tiny amounts of nitrogen in transit through ground water, lakes, and rivers, but their importance to human health and well being magnifies their importance.

The atmosphere primarily consists of Nitrogen and Oxygen gases and as such, is a reservoir of pure nitrogen gas. Other forms of nitrogen exist in the atmosphere in small amounts.

The ocean also contains all forms of nitrogen, as dissolved ions, dissolved gases, and organic matter. Dissolved nitrogen gas is most prevalent. The nitrate and ammonium ions are also present in substantial amounts, as well as dissolved and particulate organic matter.

Soils contain all forms of nitrogen, as dissolved ions, in terrestrial and dissolved gases, and organic matter. Organic nitrogen in the humus is most prevalent, followed by living tissues of plants, microbes, and animals.

Geologic reserves of nitrogen are found primarily in igneous rocks, sedimentary rocks, and coal. These reserves are largely inert, with only minor amounts reaching the active nitrogen cycle in a year.

A number of processes are considered sources of nitrate in that they access the four reservoirs to convert nitrogen into nitrate. These can be important globally or locally. Natural sources of fixed nitrogen are biological nitrogen fixation and lightning. The other substantive sources result from man's activities, either directly or indirectly, as a result of application of fertilizers, waste disposal, wood burning and fossil fuel combustion, industrial processing of nitrogen (e.g., into manufactured products), nitrogen released by domestic animals, and nitrogen fixation induced by agriculture.

Nitrate is the name given to both the solid and dissolved compound of nitrogen and oxygen which has the chemical symbol NO_3^-. Its high solubility and its stability in most aqueous environments make dissolved nitrate difficult to physically remove from potential sources of drinking water. Wherever man-made solid forms of nitrate (i.e., fertilizer) are introduced into the environment, they readily dissolve and under the proper conditions are easily carried to water supplies, often at high concentrations.

Bacteria play a primary role in the creation and transformations of "Fixed Nitrogen" which refers to all compounds of Nitrogen, except Nitrogen itself, an element that cannot be created or destroyed. "Fixed Nitrogen" is essential to all living things in small concentrations, although life-threatening in larger concentrations. Nitrogen transformations are dependent on prevailing conditions, for example, whether they take place in an oxygen-rich (aerobic) or oxygen-poor (anaerobic) environment, as well as the presence or absence of specialized forms of bacteria.

The pertinent microbiological processes that directly include the nitrate ion are nitrification, assimilation, and denitrification. The formation of nitrate from ammonia is called nitrification, primarily requiring specialized bacteria and excess oxygen. The ammonia used to create nitrate can itself be created from a number of other processes, e.g., ammonification of organic nitrogen in sewage. The elimination of nitrate through incorporation of nitrates into organic material such as plant growth is called assimilation. Organic nitrogen, however, in part remains in soil and can easily be transformed back into nitrate. Denitrification is the process that eliminates nitrate from a soil or water environment, with the loss often permanent since some of the end products, Nitrogen Gas (N_2) and Nitrous Oxide (N_2O), move readily into the atmosphere.

This flow of "Fixed Nitrogen" through the natural environment is called the Nitrogen Cycle and is illustrated in Figure 1. It should be emphasized that "Fixed Nitrogen" moves through the environment at different rates, dependent on prevailing conditions and the form it takes. For example, nitrate may move only a few feet in deep ground water over thousands of years, while nitrate released by decay of organic material can be carried to the ocean before being reassimilated.

Figure 1 emphasizes human activities and how they affect the nitrogen movement. Typically it is these activities that are of concern because, although natural processes are the

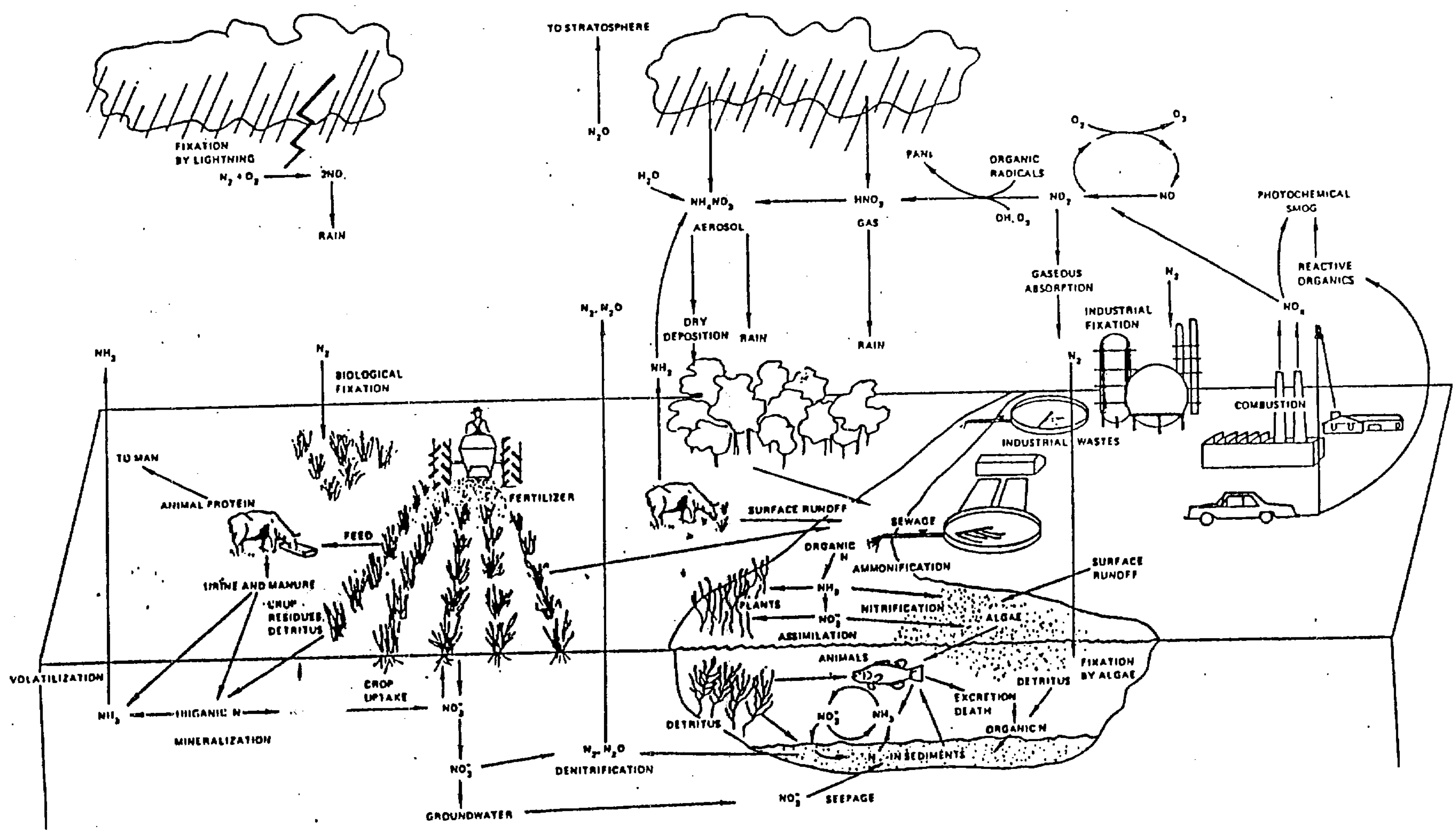

FIGURE 1 - Schematic representation of the nitrogen cycle, emphasizing human activities that affect fluxes of nitrogen. (from National Research Council, 1978)

largest source of nitrate in the environment on a global level, man's activities will exceed the natural production of nitrate both locally and regionally. These activities include promotion of the natural process of nitrogen fixation (e.g., growing legumes), application of industrial-made fertilizers, consumption of products that contain fixed nitrogen (e.g., food), and energy use (e.g., driving an automobile).

B. Measurement of Nitrate in Water

Nitrogen is present in ground water almost entirely as the nitrate ion, but minor amounts of nitrite or the ammonium ion may be present. A dual and often confusing system of reporting the nitrogen content in water is used and the utmost care must be used to insure a proper understanding of the laboratory analyses.

Nitrate can be expressed (1) on the basis of ionic weight per unit of volume or (2) as the weight of the nitrogen content. The former case yields a result nearly 4.4 times higher than the latter for the same quantity of nitrate. Therefore, the California drinking water standard or maximum contaminant level (MCL) of 45 mg/l of nitrate (NO_3^-) is nearly the equivalent of the Environmental Protection Agency (EPA) Safe Drinking Water Act Interim Health Standard of 10 mg/l for nitrate as nitrogen (NO_3^- - N). Frequently, results are reported in both values in the same text, or they are clarified as being as nitrate or as nitrate nitrogen.

In this report, data from all sources are discussed in the terms of the State of California drinking water standard which is 45 mg/l as nitrate.

C. Public Health Concerns of Nitrate

While the relationship between excessive nitrate concentrations in drinking water and the total effects on public health have been subject to controversy, it is unequivocal that excessive levels will result in methemoglobinemia in infants. Part of tl reason for controversy has been that while nitrate : itself may be relatively harmless to adults in less tha.. large quantities, the reduction of nitrate to nitrite in the stomach and the subsequent formation on N-nitrosomines appear to have the capability of adverse health effects. Definitive cause and effect relationships have, however, not been documented to this time.

The public health standards that were established for nitrate in drinking water in 1962 are based on the relationship between high nitrate in ground water and infant methemoglobinemia (the blue baby syndrome). No cases of this disease have been reported in the United States (U.S.) when the water contained less than 45 mg/l nitrate, while some reported incidents have occurred when the nitrate content has been as low as 50 mg/l. The references dealing with this subject are voluminous and will not be discussed here. A list of references is given in Appendix A of this report, "Evaluation of the Nitrate Drinking Water Standard with References to Infant Methemoglobinemia and Potential Reproductive Toxicity".

In a very simplified form, the popularly called blue baby syndrome is caused by the conversion of nitrate to nitrite in the stomach of the infant (or the direct ingestion of nitrite), and the subsequent reaction of the nitrite with hemoglobin in the blood to form methemoglobin which has a reduced capacity to carry oxygen. It is generally believed in the U.S. that levels of nitrate above 45 mg/l in drinking water can cause infant methemoglobinemia with potentially fatal results. In addition, the most recent evaluations of this health standard have shown that this standard protects against this hazard and should not be altered.

Two other health hazards which have been loosely related to high nitrate water are cancer and birth defects. To date, however, direct linkage between these hazards and nitrate has been inconclusive.

Of concern in these studies is the interaction of nitrite (again a reduction product of nitrate) with secondary amines present in the stomach to form N-nitrosoamines, certain forms of which are among the most potent carcinogens known. Almost all N-nitroso compounds tested in animals have been shown to be carcinogenic, but there is no direct evidence implicating them as human carcinogens. Of further concern is that wells which have high nitrate levels are also often the most vulnerable to pesticide contamination, and many pesticides have secondary amine structures which can theoretically react with nitrites.

Geographic investigations have been performed in Europe, the mid-western U.S., and in Asia on the possible relationship between areas where high nitrate drinking water is present and the prevailing cancer rates with inconclusive results. The difficulty in establishing any relationship stems in part from the lengthy induction period of most cancers and the relatively low exposure levels of nitrate in drinking water. In addition, the heavy use of fertilizers leading to nitrate pollution began in the relatively recent past which complicates the issue, as do the migratory habits of people in general who may have been exposed in the last decade.

In summary, there is well documented evidence of the relationship between methemoglobinemia and nitrate concentrations of over 45 mg/l in drinking water, but for other health outcomes (i.e., cancer, reproductive toxicity, etc.) there are as yet no definitive answers. As all the elements which constitute the basis for health threats seem to be present, a surge of interest has been generated by State, Federal, and worldwide organizations which may result in answers to some of the outstanding questions.

D. Economic Consequences of High Nitrate

The economic consequences of high levels of nitrate in drinking waters within California have not been comprehensively studied or estimated. Tangible costs are easily recognized however, including well relocation or deepening, nitrate removal wellhead treatment, and imported water costs for blending or replacement. Less tangible costs include land use restrictions, denial of loans for lack of a suitable water supply, and a reduced tax base.

When the nitrate level in a public water supply well reaches or exceeds the State MCL, positive steps must be taken to reduce the nitrate to an acceptable level. This may be done by blending with water from another source, either imported or from a well that delivers water that meets the State standard. The goal of lower nitrate levels may also be accomplished by deepening the well if lower nitrate levels are to be found at greater depths, or by replacing the well with a new one where nitrate levels are acceptable. The decision may also be made to close the well and reduce the supply. Deeper wells and special surface seals are being required by some county regulatory agencies where nitrate has been found to be a threat.

All of the above are expensive to the water district or supplier and the costs are subsequently passed on to the public. For example, wellhead treatment processes for nitrate removal have been estimated by the Orange County Water District to cost about $375 per million gallons. It is not unreasonable to conclude that many mi ions of dollars a year are spent to accomplish various chods of nitrate remedial measures. As an example, the total monetary funds requested of the Department of Health Services in 1986 by small and large public water systems (Table 1) for remedial measures because of nitrate violations totals $48,706,000.00. The total funds expended because of nitrate problems are substantially larger as many water systems resolved their own problems and did not apply for funding.

The less tangible costs, generally associated with land use restrictions in whatever form they take, are not easily determined. Septic tank restrictive prohibitions generally involve sewage treatment plant construction costs and sewer line construction or the tax base will be reduced from its maximum potential by restricted development. The same applies to high nitrate areas supplied by non-public water systems where proven suitable water supplies must be located before the issuance of building permits.

The economic aspects of nitrate contamination have not been analyzed to date. It would most probably prove illuminating if the overall costs to the public were examined, either as direct increased operating costs for water supplies or as indirect public expenses.

CHAPTER III
IDENTIFICATION OF NITRATE PROBLEMS IN CALIFORNIA

A. Data and Criteria Used

1. Data compilation: Numerous sources of information were utilized in the search for data on nitrate pollution in California. All nine Regional Water Quality Control Boards (Regional Boards) were contacted personally for a review of nitrate problems in their regions. All county environmental health directors were contacted by letter and by telephone requesting their cooperation in assessing areas in their jurisdiction with high nitrate levels and the probable sources. Appropriate personnel at the Department of Food and Agriculture (DFA), the Department of Health Services (DHS), the Department of Water Resources (DWR), the U.S. Geological Survey (USGS), and the U.S. Environmental Protection Agency (EPA) were contacted regarding nitrate data in their files. The numbers and counties of origin of the applications received by DHS for funds to initiate remedial measures because of nitrate violations were utilized where appropriate (Table 1). A literature search was conducted for both published and unpublished data relating to nitrate problems in California and elsewhere if the data were appropriate. Retrieval of nitrate data from the STORET data base was accomplished in-house and the figures and tables which were developed from that data are included in this report. The number of nitrate observation items (samples analyzed) in the STORET data base was 121,014 which were derived from 38,144 stations (wells). Of the total items available, 10,654 exceeded the State MCL of 45 mg/l or about 10 percent.

   Additional information was obtained from private consultants, the Soil Conservation Service, the University of California at Davis, the Agricultural Research Service, the Metropolitan Water District of southern California, the Orange County Water Distric and the Kern County Water Agency, the Monterey County Flood Control and Water Conservation District, and others.

   One concern that became apparent through conducting these efforts was that most of the data available on nitrate problems comes from the deeper municipal wells. The generally shallower individual domestic wells, of which there are tens of thousands in California, are not often tested. They are, however, more vulnerable to

TABLE 1
LOAN APPLICATIONS RECEIVED BY DEPARTMENT OF HEALTH SERVICES
FOR SOLUTION OF NITRATE PROBLEMS
UNDER SAFE DRINKING WATER BOND LAW OF 1986

SMALL SYSTEMS

COUNTY	NUMBER OF SYSTEM APPLICATIONS
Contra Costa	1
Lassen	1
Los Angeles	1
Napa	1
San Diego	1
Santa Clara	1
Trinity	1
Orange	2
Riverside	2
San Mateo	2
San Bernardino	2
San Luis Obispo	2
Santa Cruz	2
Fresno	3
Merced	3
Santa Barbara	3
San Joaquin	3
Ventura	3
Yolo	4
Sutter	6
Tulare	10
Kern	14
Monterey	22
Stanislaus	25

LARGE SYSTEMS

Contra Costa	1
San Bernardino	1
San Luis Obispo	1
Santa Clara	1
Tulare	1
Ventura	1
Kern	2
Stanislaus	4
Riverside	5
Los Angeles	6

nitrate problems because they draw their water supply from the shallower water levels that are more likely to be polluted.

Another concern was that of the decentralization of data and the lack of data evaluation. It was generally found that each jurisdictional group has relevant data but information as to its existence and its accessibility to other groups which may have an interest in specific ground water quality aspects, such as nitrate, is not readily available. Specific examples and suggested remedies are cited in another section of this report. The various collections of nitrate data are in many instances adequate for evaluation purposes, but economics prevent the evaluation and presentation of this data in usable formats.

2. Criteria Utilized: The requests from the Legislature and the Governor did not suggest specific criteria for identifying problems associated with nitrate in drinking water. Therefore, the criteria used in outlining areas of high nitrate concentrations were developed in the preparation of this report. The basic standard for problem areas caused by high nitrate waters is that of waters containing nitrate which exceeds the maximum contaminant level (MCL) of 45 mg/liter. An EPA STORET print-out on a county base map of California utilizing this minimum 45 mg/l value is included as Figure 2. The data on which this map was based is the STORET printout of all stations (wells) which had exceeded the State maximum contaminant level of 45 mg/l at some time during the time period 1975 through 1987.

In addition, it was felt that it was appropriate to examine data that evidenced human activities as shown by nitrate levels in ground water above natural background measurements. A review of recent USGS literature shows that in a nationwide statistical study natural levels of nitrate in ground water seldom exceed 10-15 mg/l, however to be conservative, an additional map prepared for this report as Figure 3 utilized a more conservative value of 20 mg/l as the lower value and 44 mg/l as the upper value and covered the time period 1975 through 1987. These values will eliminate most, but perhaps not all, natural high nitrate waters.

The figures presented in this report should be used with caution however, as there are elements that may bias the data in STORET and there is additional data available which has not been entered into STORET. The data furnished by the Regional Boards, county governmental agencies, and local agencies is not reflected on either of Figures 1 or 2 as it was generally provided in a text context. If all available data were gathered and transposed to figures similar to Figures 1 and 2, there would be substantial increases in the number of locations shown. Comparisons of the following text with the figures will reflect this.

B. Nitrate Problems by Geographic Area

1. Introduction: A decision was made to summarize the nitrate problems and present them by geographic areas having generally similar characteristics of terrain, geology, precipitation, population densities, and economic base. These intangible boundaries are not necessarily fixed or even coincident with political boundaries, but a general attempt was made to place whole counties within one geographic unit if possible. No map has been drawn outlining these boundaries as it is felt that this is not required for the intended reader and might place undue importance on otherwise generally arbitrary lines.

The reasons for attempting to summarize the data are obvious from reviewing the wide variety of formats in which nitrate data for California was found. It is found on figures of varying scales accompanying texts produced for varying purposes; integrated into general water quality texts and tables; in published and unpublished reports, Federal, State, county, and city; as computer data bases, some of which are incompatible with other computer data bases; as handwritten notes and compilations which were never completed because of funding shortages; in theses from universities; in both popular and obscure technical and scholarly publications; and in magazine and newspaper articles.

For these reasons it was felt that a summary by geographic region could best describe the general nitrate problems of each area beginning with those areas which have the most severe problems.

2. Southern California Coastal Areas: The south coastal area considered here includes all or parts of the counties of Ventura, Los Angeles, Orange, San Diego, San Bernardino, and Riverside counties. These areas exhibit somewhat common physical and socio-economic characteristics. They also all have a degree of dependance upon imported water through the City of Los Angeles and the Metropolitan Water District of southern California (MWD). A report published by MWD shows that at least 344 wells, or about 12 percent of the wells sampled in its service area, exceed the State

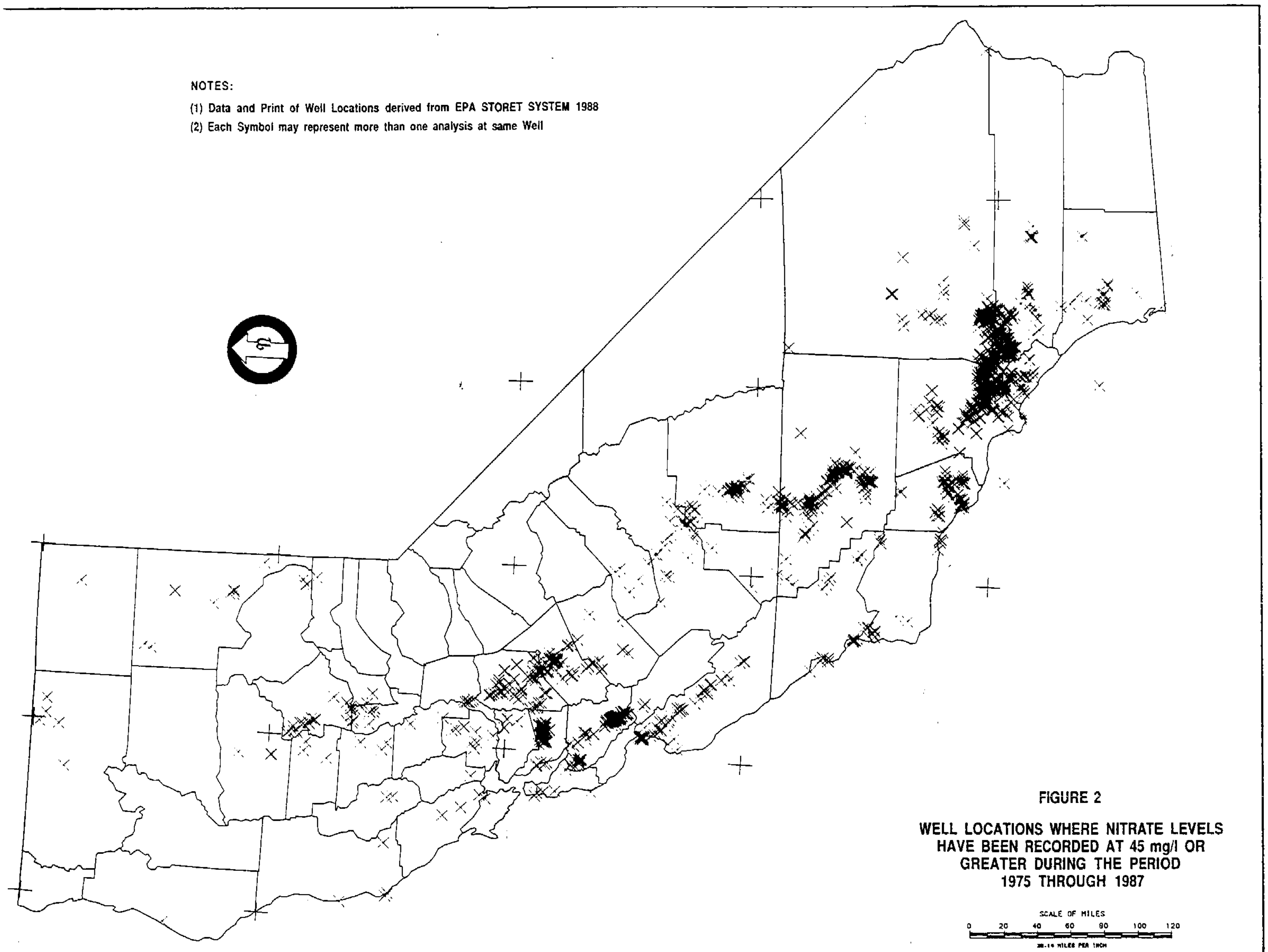

FIGURE 2

WELL LOCATIONS WHERE NITRATE LEVELS HAVE BEEN RECORDED AT 45 mg/l OR GREATER DURING THE PERIOD 1975 THROUGH 1987

NOTES:

(1) Data and Print of Well Locations derived from EPA STORET SYSTEM 1988

(2) Each Symbol may represent more than one analysis at same Well

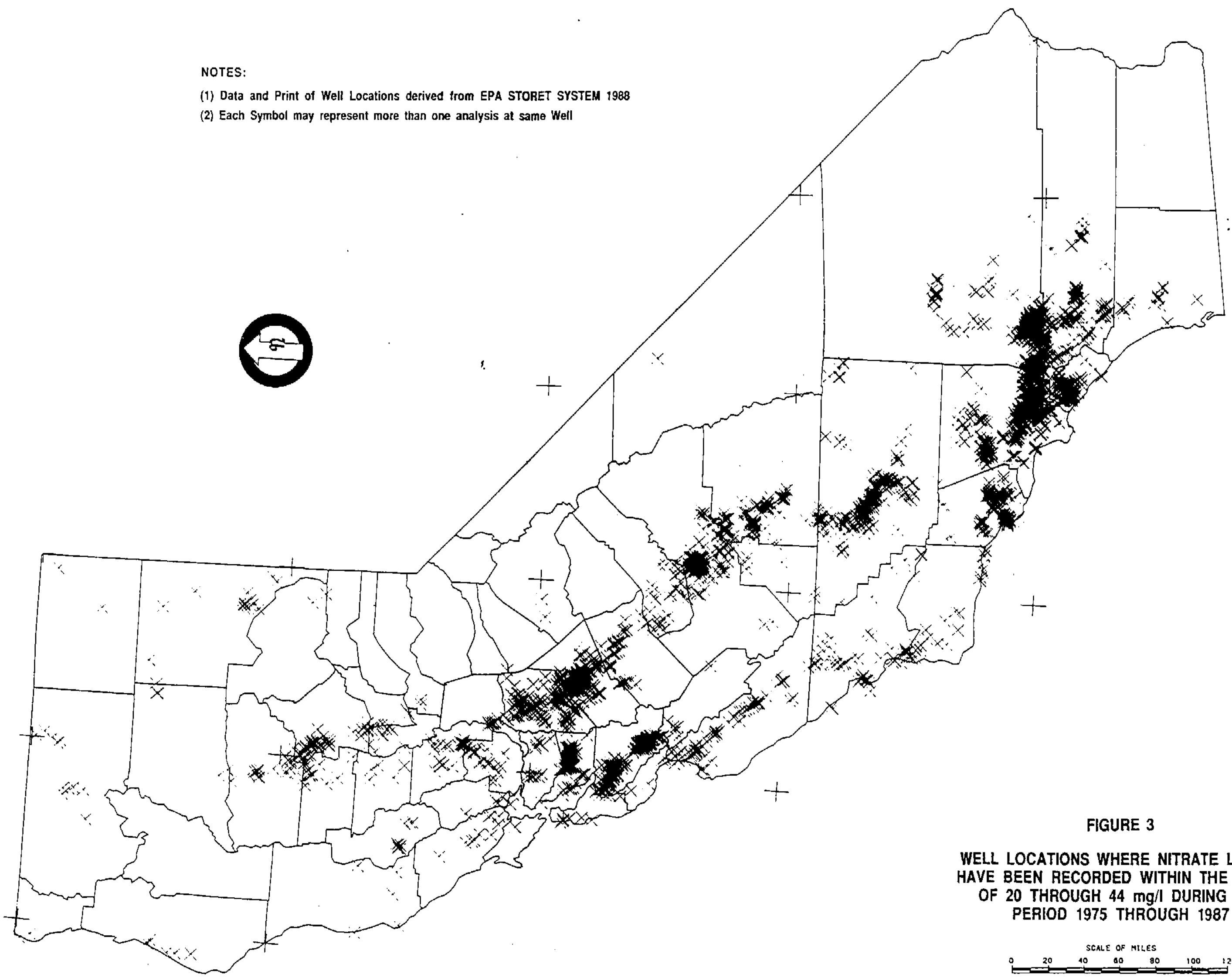

FIGURE 3

WELL LOCATIONS WHERE NITRATE LEVELS HAVE BEEN RECORDED WITHIN THE RANGE OF 20 THROUGH 44 mg/l DURING THE PERIOD 1975 THROUGH 1987

MCL for nitrate. The loss of ground water production for domestic use from increased total dissolved solids and nitrate, the majority of which is nitrate, is about 43,000 acre-feet/year, or about 4 percent of the annual production of this area. This may be contrasted with the highly publicized organic chemical spills which have reduced the ground water production in the area about 0.5 percent to date.

With the decline of intensive agriculture and installation of sewage systems and treatment plants to serve a more urban population, this trend of ground water degradation may be arrested in time. Contrarily, should the population increase and consequent water demand continue without available additional imported supplies, dependence on the already contaminated ground water may increase.

a. Orange County - In Orange County the nitrate problem has been recognized early and action has been initiated by the Orange County Water District. Nitrate concentrations exceeding the State MCL of 45 mg/l affect about 250,000 acre-feet of ground water underlying about 22 square miles. The high nitrate ground water is found primarily in shallow aquifers underlying Westminster, Garden Grove, Tustin, Fullerton, Anaheim, and Irvine. Ninteen eighty-seven (1987) data shows that an estimated 51 municipal wells have been shut down because of high nitrate and about 13 other wells produce water which must be blended for use as municipal supplies.

   The primary source of nitrogen loads into Orange County is from wastewater treatment plant discharges, dairy runoff, and rising ground waters originating in the upper Santa Ana Basin. Other suspected contributors within Orange County to the high nitrate problem include other human activities, e.g., sewage leachfields, industrial operations, dairies, landscaping, and other fertilizer-intensive agricultural operations.

   The Orange County Water District is constructing a wellhead nitrate removal facility in Tustin with an expected completion date of September 1988. This facility will consist of an Ion Exchange Process and a Reverse Osmosis Process and will produce about 3,000 acre feet/year of blended water at an estimated cost of $220 an acre-foot including capital and operation and maintenance costs. In addition, the District plans to set up a similar facility in Garden Grove utilizing two more Reverse

Osmosis plants and two more Ion Exchange plants it has acquired from DWR.

b. The Upper Santa Ana Watershed - The Upper Santa Ana River watershed is located in the southwest corner of San Bernardino County, in western Riverside County, and the very eastern part of Los Angeles County. It includes the prominent Chino, Riverside-Arlington, Temescal, Elsinore, and Bunker Hill ground water basins which have historically been heavily utilized for agriculture and municipal purposes.

(1) The Bunker Hill Basin in San Bernardino County has nitrates in ground water exceeding the State MCL in the historically agricultural areas of San Bernardino, Redlands, Highlands, East Highlands, Loma Linda, and adjacent to the Santa Ana River. Studies by the USGS have implied that past agricultural practices and sewage treatment facilities are primarily responsible for the elevated nitrate levels found in the upper ground water zones (less than 500 feet deep). Acceptable levels of nitrate were found to be present in the lower ground water zones (more than 500 feet deep). The City of Riverside, which relocated its wells to this area because of nitrate in the Riverside Basin, has again had some impact from nitrate which required replacement wells.

(2) The Riverside-Arlington and the lower Temescal ground water basins are characterized totally by poor quality ground water as a result of past agricultural use and reuse. Nitrate exceeds 45 mg/l throughout the basins and the City of Riverside has closed most of its production wells for municipal uses and now derives 80 percent of its water from the Bunker Hill Basin. The City of Corona is about 50 percent dependent on ground water from the Temescal Basin and must buy imported water to blend with its supply to achieve an acceptable quality. The upper Temescal and Elsinore Basins still have very good quality water with the exception of one small area found to have exceeded the State nitrate standards.

Within the Riverside, Temescal, Arlington, and Elsinore basins 64 out of the remaining 141 municipal wells exceed the State MCL for total dissolved solids and nitrate in drinking water.

Of the 64 wells, 39 have been closed, 11 are used with blended water, nine are for non-potable uses, four are operated above drinking water standards, and one is on standby. It is estimated that the water districts will have to buy an additional 12,000 acre-feet/year of MWD imported water. A proposed desalting plant is to be built in the Arlington Ground Water Basin for the recovery of ground water resources to assist in relieving this extra demand. Five large water systems have requested financial aid under the Safe Drinking Water Bond Law of 1986 because of nitrate.

(3) The Chino Basin is an adjudicated basin in the western part of San Bernardino County and the northwestern part of Riverside County. Currently, ground water supplies 100 percent of the agricultural need and almost 90 percent of the municipal and industrial uses for the cities of Upland, Montclair, Ontario, Chino, Norco, and Fontana. Nitrate levels exceeding drinking water standards occur in 89 of 860 wells in the basin however only three were closed. Municipal wells have been replaced elsewhere in the basin or blending has occurred to produce acceptable water. The high nitrate levels in the northern part of the basin are attributed to historic agricultural uses and practices, and the excessive nitrate in the southern part of the basin are attributed to the extensive dairy industry. Projections for nitrate values for the Chino Basin as provided through ground water modeling sponsored by MWD suggest that approximately one-half of the basin will have nitrate levels exceeding the State MCL of 45 mg/l by the year 2045, with or without a proposed conjunctive use ground water storage program. At present, however, though a large part of the basin contains nitrate in excess of the State MCL, costly replacement wells are still possible and the production of water suitable for blending is feasible.

c. Los Angeles County Basins - The Los Angeles County basins, which include the upper Los Angeles River Basin, the San Gabriel Basin, the Raymond Basin, the Claremont Heights, Live Oak, Pomona, and Spadra Basins, and the Santa Monica, Beverly Hills, Central, and West Coast Basins, have been affected with water from 108 municipal wells exceeding the State MCL for nitrate. Six large water systems have requested financial aid to renovate their works.

(1) In the upper Los Angeles River Basin, the Verdugo Subbasin which underlies parts of Glendale, La Cresenta, and Los Angeles is strongly affected by nitrate. Thirteen municipal wells currently must use imported water for blending. An ion exchange plant is proposed to recover the poor quality water and in part replace the imported water. This in-situ poor quality water is believed to have been caused by past septic tank practices.

(2) The large scale use of septic tank disposal systems is also the source of high nitrate waters in the La Canada and Altadena areas in the Raymond Basin. Fifteen municipal wells have been affected and blending water is prevalent.

(3) Approximately one-quarter of the San Gabriel/ Puente Basin contains ground water exceeding the State MCL for nitrate, which affects 55 municipal wells in Alhambra, San Marino, La Puente, and Covina. As there are presently no unsewered areas or agricultural activities, it is suspected that past practices of both are the cause. Blending with imported water and replacement wells installed in other parts of the basin are the remedial measures used presently.

(4) Large areas where nitrate exceeds the State MCL are present in the Pomona and Live Oak Basins with a somewhat less area in the Claremont Heights and Spadra Basins. These are believed to be the result of a long history of agricultural activities. Twenty municipal wells in Pomona, La Verne, and Claremont have been affected and blending is required to meet drinking water standards.

(5) The Los Angeles Central, the Santa Monica, West Coast, and Beverly Hills Basins are essentially free of nitrate problems. One small area of nitrate from an unknown source is present in the Montebello Forebay area.

(6) In a rural area in the northern part of Los Angeles County known as Aqua Dulce, nitrate

has become a concern in ground water. Of the seventeen small water system wells, five exceed the State MCL and if historical trends continue as indicated, eleven will exceed the MCL within three years.

d. San Diego County - San Diego County has probably least noticed the effects of nitrate contamination for the very reason of its strong dependence on imported surface water supplies. Degradation of ground water is occurring but unless the impact is felt by public water system users, it may pass unnoticed for lengthy periods of time. In 1987, nine public water systems exceeded the State MCL for nitrate.

The small coastal basins are very vulnerable to ground water degradation, a measure of which has already occurred. Three areas have experienced nitrate contamination at such a degree that new water well ordinances enacted function as potential prohibitions for building permits. These areas are the San Marcos-Twin Oaks Valley area, Escondito-San Pasqual Valley area, and parts of the Ramona Basin. Additional areas where nitrate has been found to exceed the State MCL are in the Tijuana Basin, the El Cajon Basin, the San Luis Rey Bonsall Basin, the Poway Basin. the Morena and Carmel Valleys, and the Vista Hydrographic subarea.

No specific source investigations have been accomplished in any of these areas, however, they have all had historic land uses of agricultural food crops, poultry ranches, and dairies. Public water and sewer services are available in the more urbanized areas; however, in several basins, ground water is utilized as a water source and septic tanks for waste disposal.

e. Ventura County - The main basins in Ventura County, the Ventura River Basin, the Santa Clara River Basin, the Los Posas, Santa Rosa, and the Oxnard Plain, all have experienced elevated nitrate problems. Isolated wells in the Ojai area in the Ventura River Basin have exceeded State action levels for nitrate, as have wells near Santa Paula and Fillmore in the Santa Clara Basin. The Los Posas Basin has only isolated instances of elevated nitrate near Moorpark and Somis, however, the Santa Rosa Basin must limit ground water extraction for drinking water purposes because of high nitrate and total dissolved solids. In the

Oxnard Plain, both the upper and lower aquifer have experienced elevated nitrate in the area of Oxnard.

It is expected that as wells go out of service because of nitrate, an additional 3,000 acre-feet of imported water will be required for blending or for replacement purposes to meet State water quality standards for drinking water. Four Ventura County small water systems have applied for funds to rehabilitate their systems because of nitrate.

3. <u>San Joaquin Valley</u>: The San Joaquin Valley is the southern part of the Great Valley of California and is found in all or parts of the following counties: San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern. In general, the Valley has two major ground water units; a shallower unconfined system along the eastern border, and a deeper confined system in the central and western portion.

The eastern border of the valley generally has sandier, more permeable soils than the central and western part of the valley. These eastern areas first developed an agricultural base utilizing surface water supplies where possible. Later agricultural development spread to the drier, less permeable soils in the central and western parts of the Valley utilizing the confined ground water as an irrigation source. As the largest changes in ground water elevations have been found in the confined aquifer, and as it also has the most economic importance, this aquifer has a degree of priority in monitoring programs. However, it has been shown many times in California and nationwide that nitrate problems are primarily found in the shallower wells and that with exceptions, decrease with depth into the water table. Those exceptions are generally where improper well construction allows the shallow water to be drawn downward into the lower aquifer or where unusually deep pumping cones of depression draw the upper waters downward to mix with lower waters.

The possibility exists that with somewhat biased monitoring in the San Joaquin Valley, an accurate picture of the nitrate problem in the San Joaquin Valley might not be evolving. Selective nitrate studies in the San Joaquin Valley initiated by special requests have all shown that a larger nitrate problem than previously thought exists in each of those areas. Examples are the Delano Investigation (DWR-Bulletin 143-6), the Hilmar Investigation in progress (Central Valley Regional Board), and the Kern County Ground Water Quality Report (KCWA-March 1982).

a. San Joaquin County - Nine small water systems in this county exceeded the State maximum contaminant level for nitrate during the year 1987. Corrective actions were initiated and all users notified. Three small water systems applied to DHS for funds to assist them in reaching compliance with their systems. During this same year (1987), the EPA data files show three violations occurring in San Joaquin County.

   Nitrate exceeding the State maximum contaminant level in San Joaquin County appears to be more concentrated in the vicinities of Lodi, the Manteca/Ripon/Escalon area, and the Tracy area on the west side of the Valley. The San Joaquin Health District, Division of Environmental Health has set restrictions on well construction in Tracy and Manteca requiring well sealing by surface grouting to greater depths.

   The causes of the elevated nitrate levels have not been determined but are suspected to be related to the application of chemicals and fertilizers by agricultural interests and to poultry and dairy wastes.

b. Stanislaus County - Twenty five small water systems and four large water systems requested financial aid from Department of Health Services in 1987 to remedy nitrate problems. These requests for aid come from such varied sources as cities, trailer parks, and schools. Twenty three of these requests are in the area along State Highway 99 from Modesto through Turlock and to the east from Denair through Hughson to Oakdale. One request was from the west side of the San Joaquin Valley at Patterson. On the west side of the Valley, nitrate exceeding the State MCL has also been recorded near Wesley and Crows Landing. It is believed that most of these occurrences are the result of agricultural activities in the sandy soil and high water table zone.

c. Merced County - In Merced County only three small public water systems have applied to DHS for financial aid to solve their nitrate problems, however, information from the Merced County Department of Environmental Health shows that in recent years no less than 19 public water systems have had to take remedial measures to meet drinking water standards.

Existing problems appear to be most pronounced along and on both sides of Highway 99 through the County. Atwater, Winton, Livingston, Delhi, and Hilmar have all been affected by high nitrate ground water. A study of the Hilmar area being conducted by the Regional Water Quality Control Board has shown that within an approximately 30 square mile area, about 60 percent of the 69 wells sampled exceed the State MCL for nitrate. These high nitrate levels are tentatively attributed to leachate from dairy wastes and from agriculture.

On the western side of Merced County, nitrates exceeding the State MCL has been found from Newman to Guistine, around Los Banos, and near south Dos Palos.

d. Madera County - There appear to be fewer problems in Madera County from elevated nitrate. Three areas which have nitrate levels well above background levels are to be found around the Chowchilla area, the Dairyland/Berenda area, and along the border of the San Joaquin River near Ripperdan. Identification of the sources for the elevated nitrate has not been made.

e. Fresno County - Local ground water analyses having nitrate values that range from above background levels to above the State MCL have been recognized in Fresno County for many years. Numerous small and generally unrelated studies dealing with nitrate problems have been made in the Fresno-Clovis area for various academic purposes, but no single countywide evaluation has been made for the purpose of determining the occurrence and sources of elevated nitrate in ground water.

   Past studies of the Fresno-Clovis areas show that elevated nitrate levels are present throughout the city and to the west. These studies have independently targeted septic tanks, winery wastes, use of fertilizers, and urban runoff wells as nitrate sources.

   Other areas in Fresno County where nitrate exceeds the State MCL have been found on the east side of the valley in the Raisin City-Carruthers area, Laton through Kingsburg, and throughout the Reedley-Orange Cove areas. The most probable sources of these occurrences are agricultural activities.

Areas in Fresno County on the west side of the valley where nitrate is above the State MCL are the Mendota-Firebaugh area, Kerman, the Cantua Creek area, and the Coalinga area. These, also, have most probably been influenced by agricultural activities although there are deposits of naturally occurring high nitrate soils along the western edge of the Valley in Fresno County.

f. Kings County - Kings County appears to be relatively free of high nitrate concentrations with the exception of historic isolated occurrences around the Hanford-Lemoore areas and in the Avenal area on the west side of the Kettleman Hills.

g. Tulare County - Along the eastern border of that part of the San Joaquin Valley in Tulare County is a discontinuous belt of high nitrate ground water which extends from Reedley in Fresno County southward through Tulare County past Delano-McFarland-Bakersfield in Kern County. This ill-defined belt appears to be associated with orchard, citrus, and other agricultural crops in Tulare County and a zone of loose, permeable sandy soils. Thirty-three small and one large public water systems in Tulare County have been in violation of drinking water standards because of nitrate within the general boundaries of this zone. Ten have applied to DHS for financial aid in renovating their systems.

Areas which have been affected include Dinuba, Yettem, Lemon Cove, Woodlake, Lindsey, Strathmore, Porterville, Ducor, and Richgrove. Other isolated areas of high nitrate in Tulare County have occurred near Traver, Goshen, Visalia, and Tulare.

h. Kern County - The continuation of the discontinuous belt of high nitrate waters as described in Tulare County continues through Kern County. Ground waters containing nitrate, some of which are more than twice as high as the State MCL, are found through Kern County near Delano, McFarland, Wasco-Shafter, Famosa, Rosedale, Bakersfield, Arvin-Edison, Lamont, and along the southern border of the Kern Lake bed. Very high nitrate levels have also been found along the western border of the Buena Vista Lake bed near Maricopa and Taft and northwest of Lost Hills.

Thirty-four small public water systems have exceeded the State MCL for nitrate at one time or another, of which 19 continue to exceed the standards. Fourteen small water systems and two large water systems in Kern County applied to DHS in 1987 for financial assistance to remedy their nitrate problems.

In a 1982 ground water quality study performed by the Kern County Health Department and the Kern County Water Agency, it was shown that the areas of greatest nitrate concentration in the unconfined ground waters were found to be in the sandy soils along the east side of the basin where the agricultural development began many years ago. Areas where nitrate levels approach or exceed the State MCL increased in size from an estimated 49 square miles in 1958 to 372 square miles in 1979.

Nitrate contaminated areas are found also in the confined aquifer system near the eastern edge of the confining clay layer where intercommunication of the upper and lower ground water bodies is most apt to occur. In 1979, ground waters in the confined aquifer underlying 45 square miles were approaching or had already exceeded the State MCL for nitrate.

4. <u>Sacramento Valley</u>: The impact of irrigated agriculture has been intensively studied in the Great Central Valley of which the Sacramento Valley constitutes the northern part. For this report, this area consists of all or part of the following counties: Tehama, Butte, Glenn, Lake, Colusa, Sutter, Yolo, and Sacramento. USGS studies (1984) of about 700 wells in this area, of which 62 with long-term records were statistically analyzed, have concluded that nearly one-third of the wells in the Sacramento Valley may be undergoing significant increases in nitrate concentrations. Data suggests the following are the most possible sources: 1) surface contamination in shallow wells; 2) pollution from septic systems; and 3) leaching of fertilizers applied to croplands, particularly orchard areas.

   All of these counties were considered by the USGS to contain potential elevated nitrate concentrations with the exception of Lake County. Nitrate concentrations exceeding drinking water standards have severely impacted Chico and Sutter City, and less severely impacted the Knights Landing/Arbuckle, Yuba City-Gridley, Williams, Red Bluff, and Corning areas.

   To prevent further contamination in the Chico area of Butte County, an action plan has been enacted limiting development and restricting the use of septic tank systems for sewage disposal until expansion of the existing sewer systems has been accomplished.

In Sutter County in 1986, about 20 small public water well systems had nitrate levels over the State MCL of 45 mg/l. Some of these wells were shallow, but others were as deep as deemed safe, for deeper wells in parts of this county may encounter arsenic and other problems. In 1986, six public water systems applied to DHS for financial assistance to remedy nitrate problems. A limited sampling of the numerous private wells in use in Sutter County was conducted by the Sutter Environmental Health Department and indicated that about 75 percent of the sample group were over the State MCL.

In Tehama County, nitrate exceeding the State MCL has been found in the Red Bluff suburbs on the east bank of the Sacramento River. The critical problem area is not extensive at this time, however, continuing development with additional housing and individual waste disposal systems is occurring. In a DWR study of this area, "Antelope Ground Water Study," evidence was presented of recycling taking place between individual wells and waste disposal systems.

Four small public water systems in Yolo County applied to DHS in 1986 for assistance in solving nitrate problems.

There appears to be no immediate threat to drinking water supplies from nitrate pollution in Sacramento County. EPA printouts of nitrate violations for the years 1982 and 1983 show that several small water systems serving motel and trailer parks were in violation. No violations have been recorded in either EPA or DHS data banks since that time.

5. <u>The Central Coastal Area</u>: The Central Coastal Area is defined as the counties of Santa Cruz, San Benito, Monterey, San Luis Obispo, and Santa Barbara.

   a. Santa Cruz County - A study of the Pajaro Valley initiated by University of California Santa Cruz students in 1972 with follow-ups by the Santa Cruz County Environmental Health Department show that a significant part of the Valley contains ground water in which nitrate exceeds State MCL. It has been suggested that over-fertilization in sandy soils combined with improper well construction and abandonment may be responsible for the larger part of the ground water degradation. It has been suggested by the County Environmental Health Department that about one well in four in this area exceeds the MCL of 45 mg/l for nitrate. The public is notified by the Environmental Health Department in Santa Cruz County if it is suspected they are at risk.

Other areas in Santa Cruz County which have experienced elevated nitrate levels are the San Lorenzo Valley, an area in mid-county served by the Central Water District, and the Scotts Valley area. These areas are most probably experiencing high nitrate levels from septic tank waste disposal systems.

A generalized background picture of the nitrate problem is not available for Santa Cruz County to determine the significance of what may be occurring.

b. San Benito County - Information on only one occurrence of nitrate above the State MCL was found in San Benito County. This was at the site of a former turkey ranch east of Hollister. This ranch, and the site of a neighboring explosive testing firm, were both formerly dairy operations. Nitrate levels at these sites ranged from 482 to 570 mg/l and are above 100 mg/l at a distance of 3/4 of a mile. This area services no public water system at present and has not been considered a public risk by the County Sanitary Engineer.

c. Monterey County - The Salinas River Valley communities in Monterey County have been severely impacted by elevated nitrate in ground water as have been other communities in the northern end of the county. As very little surface water is used to supply drinking water in Monterey County, the major source is from ground water. The County also has more small water systems than any other county in California which increases the vulnerability of the supply. In the event of ground water degradation, small water systems seldom have the options available to large systems without government financial assistance. In 1986, twenty-two small water systems from Monterey County applied to DHS for financial assistance under the Safe Drinking Water Bond Law.

Within the County, 113 of 1,207 wells of the small public water systems (under 200 connections) were in violation of drinking water standards for nitrate during the year 1986. Six of 180 wells serving large water systems (over 200 connections) were closed because of nitrate. New real estate developments are required to furnish proof of adequate water to the County Health Department prior to the issuing of building permits.

Data from studies prepared by the Monterey County Flood Control and Water Conservation District show that, at present, 48 percent of all monitored wells in the unconfined aquifer areas of the Salinas Valley exceed the drinking water standard of 45 mg/l for nitrate. Further, based on the trend of the last ten years, they project that the mean nitrate concentration will exceed the drinking water standard by 1.9 to 4.4 times in all the Salinas Valley unconfined aquifer subareas by the year 2000. Probable sources are attributed in most part to agriculturally related activities.

A directive by the County Board of Supervisors in 1985 initiated a ground water quality study in the Prunedale area. Of the 154 private and public wells serving the area, 27 percent exceeded the maximum contaminant level of 45 mg/l, 3 percent were between 40-45 mg/l, and 17 percent were between 30-40 mg/l. Contamination was occurring in both private and public water systems and in both shallow and deep aquifers.

Data from the County Environmental Health Department show high nitrate in the Salinas River Valley in the areas of San Ardo to San Lucas, the King City area, Greenfield/Soledad/Gonzales on the east of the river, Soledad to Salinas on the west of the river, areas surrounding Salinas, and in the vicinities of Santa Rita, Prunedale, Moss Landing, and Los Lomas.

d. San Luis Obispo - Areas in San Luis Obispo County where the nitrate levels have been found exceeding the State drinking water standards of 45 mg/l include Arroyo Grande, Oceano, Tri-Cities Mesa, Grover City, Morro Bay, Los Osos, Baywood, Cayucos, Pismo Beach, and Cuyama.

   In the area of Arroyo Grande/Oceano/Grover City, nitrate levels commonly are higher than the State drinking water standard. The past use septic tanks and the widespread application of commercial fertilizers are believed to be major sources. A large portion of the Arroyo Grande, Oceana, and Grover City areas are now served by community sewer systems. Poorly constructed shallow wells and past well abandonment practices appear to allow continuing degradation. Septic tank use prohibitions which act as land use restrictions are in effect within the County.

e. Santa Barbara County - In Santa Barbara County, the Santa Maria and the Santa Ynez River Valleys have received the most impact from elevated nitrate levels. The Santa Maria Valley, both up and downstream of the City of Santa Maria, contains ground water which substantially exceeds the MCL for nitrate. This has been attributed by USGS to both non-point agricultural sources and to point sources such as industrial and municipal returns. Of the 20 County permitted small water systems in the Santa Maria Basin, six have shown elevated levels of nitrate and three are being treated for exceeding the State drinking water standards for nitrate.

   In the Santa Ynez River Basin, ground waters containing nitrate in excess of the State MCL have been found in the past in the areas of Lompoc, Buellton, Solvang, and Los Olivos. Currently, no small water systems in these areas exceed the State MCL. Agricultural activities have been named by the USGS as the primary causes although with a shifting emphasis to urbanization, individual waste disposal systems will become relatively more significant in the future.

6. <u>The San Francisco Bay Area</u>: The Bay Area counties which consist of Sonoma, Marin, Napa, Solano, Contra Costa, Alameda, Santa Clara, San Mateo, and San Francisco have historically, with the exception of the latter, been partially to wholly agricultural but are rapidly becoming urbanized. They are served by a multiplicity of large and small water systems and individual domestic wells. Sewer systems and treatment plants handle the bulk of sewage from the urbanized areas however some commuter suburbs are still served by septic tanks.

   a. Sonoma County - Areas in Sonoma County where nitrate values exceed the State MCL are in west and east Petaluma, east Rohnert Park, and south Sebastopol.

      The west Petaluma area became the subject of a DWR study (1982) after the diagnosis of a case of infant methemoglobinemia (blue baby). The Petaluma study was to determine the source and magnitude of the nitrate problem. It was determined that ground water contamination was caused by the leachate from the wastes of an extensive historic poultry and dairy industry. The present day individual ranchettes were served by shallow individual domestic wells which drew water from the contaminated zone.

In the east Rohnert Park area ongoing studies may result in building moratoriums or additional well sealing requirements should nitrate problems continue or accelerate. The east Petaluma and Sebastopol areas have had historic land use similar to that of west Petaluma (dairies and poultry farms), and are also exhibiting elevated nitrate levels in ground water. Isolated instances have been noted elsewhere in Sonoma County where septic tank waste disposal is the probable cause.

b. Napa County - In Napa County, isolated areas of nitrate which exceeds the State MCL have been found in the Napa Valley proper from south St. Helena to Rutherford. Continued monitoring is scheduled in 1988-89 for this area, and additional monitoring will be expanded County-wide.

c. Solano County - In Solano County, areas east of Vacaville and Winters were found in the past to contain ground water in which nitrate exceeded the 45 mg/l State MCL. No specific causes have been determined, but the land uses of these areas have historically been agriculture and orchards. Similar isolated instances are to be found around Vallejo, Benecia, and south and east of Fairfield.

d. Contra Costa County - Nitrate exceeding State drinking water standards has been a continuing problem in the Brentwood-Byron-Knightsen agricultural areas, necessitating closing some of the large water system wells and requiring blending with imported water in others. In the Knightsen area, over 90 percent of the shallow wells tested contain excess nitrate, however, deep wells (over 150 feet deep) have low nitrate values. Isolated occurrences of excessive nitrate have been recorded in the Concord/Clayton Valley/Walnut Creek areas, however few individual domestic wells are still used for drinking water purposes. Contra Costa County has received funding for two projects to remedy nitrate problems in the Knightson area.

e. Alameda County - There are two primary areas where the nitrate levels in ground water exceed the State MCL in Alameda County. These areas are the

Livermore Valley and the eastern shore of San Francisco Bay from Fremont north through San Leandro.

The Livermore Valley area of high nitrate extends from Altamont Pass west through Livermore and south into Arroyo Mocho, with several other small areas extending from Pleasanton to Dublin. The main contributors to these high nitrate ground water zones are two fold; past agricultural practices and the historical presence of individual septic tank disposal systems. However, the effects of the disposal of effluent and sludge between 1926 and 1959 at the old Livermore sewage treatment plant appears to have affected the water quality of the upper and lower aquifers. One well in the near vicinity has been shut down by the purveyor due to nitrate concentrations. Water from two other wells in the area is being blended to reduce nitrate concentrations.

The other major area in Alameda County, the eastern San Francisco Bayshore, was historically devoted to row-crop agriculture and orchards prior to low intensity housing development utilizing septic tank disposal systems. While intense urbanization is now present, accompanied by the development of sewer systems and treatment plants, the presence of high nitrate ground water remains.

f. Santa Clara County - Santa Clara County has had a history of high nitrate levels in the southern part of the county. The two most impacted areas are near Old Gilroy and Morgan Hill. Suspected causes are septic tank waste disposal in high water table areas and the agricultural history. Random occurrences are found to occur northward into the San Jose area. EPA records show that the City of Morgan Hill water system has wells which have repeatedly been in violation of the State MCL for nitrate since at least 1982. Two water companies have applied to DHS for financial assistance to rehabilitate their water systems because of nitrate exceeding drinking water standards.

g. San Mateo, San Francisco, Marin Counties - With the exception of the Pescadero area in San Mateo County, nitrate does not appear to be a problem in these counties. During 1974, tests of Pescadero well systems showed that 41 percent of the systems produced water containing nitrate in excess of the

State MCL. Public notices alerting the citizens have been distributed by the Environmental Health Department of San Mateo County explaining the nitrate problem and the consequences of drinking these waters. The suspected causes are failures of old septic tank waste disposal systems and fertilizers.

7. North Coast Area: Generally the north coast area, consisting of Del Norte, Humboldt, Mendocino, and Trinity counties, has relatively few nitrate problems. The most probable reasons for this are that little intensive irrigated agriculture is practiced, a relatively high rainfall prevails, and a low population base is present.

   In Humboldt and Del Norte Counties all public water systems have been sampled for nitrate by both the DHS and the county health department. No elevated nitrate levels have been found. Little attention has been focused on coastal ground water basins because of the limited quantity of ground water and the marginal water quality because of the presence of iron and manganese. The exception to this is the Smith River ground water basin where nitrate levels recently measured by the Regional Water Quality Control Board have exceeded the drinking water standards in 14 percent of the domestic wells sampled. These wells are shallow, may not have surface seals, and are generally in the immediate vicinity of either heavily fertilized lily bulb fields or dairy operations.

   Somewhat elevated nitrate levels were also noted by the county health department near an experimental fish composting operation in Mendocino County.

   Basic ground water quality data is not abundant for the north coast region other than that gathered for the public water systems being monitored by DHS and the county health departments. The small coastal basins are particularly vulnerable to nitrate contamination however should intensive development occur without accompanying sewage treatment plants, or should intensive nitrate contributors such as feedlots, poultry ranches, dairies, or fertilizer intensive agriculture enter the basins.

8. Northeastern Counties: The northeastern counties of Siskiyou, Modoc, Shasta, Lassen, and Plumas have had only minor occurrences of nitrate problems which have been usually related to septic tank waste discharge systems. With development, further problems of the same nature can occur as much of this area is covered by

shallow soil overlying permeable volcanic rocks thus allowing neither adequate time nor filtered travel distance for adequate waste discharge treatment.

The area of east Quincy in Plumas County is experiencing nitrate problems from septic tank systems, as is the east shore of Lake Almanor from the same cause. In Lassen County, nitrate problems have been experienced near Eagle Lake, Honey Lake, and Doyle. The problem of septic tank use with shallow water tables at Eagle Lake has been under review by government agencies for sometime and has led to prohibitions. Building moratoriums and other options have also been considered. In Siskiyou County, three areas near Yreka, Weed, and Macdoel have been observed for some time and have been contained through septic tank and land use restrictions. An individual occurrence has been reported in Modoc County near Likely.

9. Mountain Counties: Part or all of the following counties fall into the mountainous terrain of the Sierra Nevada Range: Sierra, Nevada, Placer, El Dorado, Amador, Alpine, Calaveras, Tuolumne, Mariposa, Madera, Fresno, Tulare, and Kern. As good quality surface water is generally the source of drinking water for public water systems in the mountains and private domestic wells are not commonly sampled and tested, little information is available on ground water quality.

   The STORET printout of geographic locations where nitrate has been recorded as exceeding drinking water standards shows that no nitrate violations were recorded in these mountainous areas. Similarly, no requests were filed with DHS for assistance in rehabilitation, treatment, or replacement of any public water systems.

   Some instances of excessive nitrate in ground water were furnished by the County Environmental Health Directors Offices. In Tuolumne County, in the area of Chinese Camp west of Jamestown, wells in which nitrates have consistently exceeded the State MCL of 45 mg/l have been identified since at least 1979. A new well was drilled for a school and bottled water is furnished at a mill. Elevated nitrate levels which are thought to be naturally occurring are present in the vicinity of Angels Camp.

10. Desert Areas: The desert areas which are defined as all or parts of the counties of Mono, Inyo, northern Los Angeles, San Bernardino, eastern Kern, eastern

Riverside, eastern San Diego, and Imperial have isolated nitrate problems. Most are probably related to one or more causes; septic tank and seepage pit practices, intensive dairy/feedlot operations, and agricultural practices. Golf courses which are fertilizer intensive and generally follow development must also be considered as a source of nitrate in the ground water.

In San Bernardino County, nitrate contamination related to septic tank practices is present in the Crestline area, the Halloran Springs area, and the Yermo area. Along the Mojave River, nitrate levels which exceed drinking water standards are related to dairy wastes. However, the largest threat to degradation of drinking water exists in the Victor Valley area where a 90-100,000 population resides in a concentrated area on small rural unsewered lots. It has been estimated that 20 percent of the recharge to the aquifer is from sewage effluent. A current USGS/State Board study is underway to determine the effects of the existing septic tank and seepage pit practices on the ground water quality.

Other reported areas where nitrate has exceeded drinking water standards are the Littlerock area south of Palmdale in northern Los Angeles County, and along the Mojave River in San Bernardino County. In eastern Riverside County, the Hemet area and the Moreno area have been affected by high levels of nitrate which exceed drinking water standards, probably from past agricultural practices. Cathedral City near Palm Springs has historically had wells from which water sample test results exceed the State MCL for nitrate. This is believed by the Colorado River Basin Regional Board to be caused from the septic tank sewage disposal methods practiced there. Sewage disposal practices are also believed to be responsible for high nitrate levels in ground water in the Romoland-Homeland area of Riverside County. Small areas of high nitrates have been mapped near dairies and poultry farms south of the Winchester area. The Anza-Borrega area in eastern San Diego County has nitrate in well water which exceeds the State MCL for drinking water. Agricultural practices and septic tank practices are the suspected cause.

C. Summary of Sources of Nitrate

1. Nitrate in Surface Waters: A summary printout was extracted from the STORET data base of the surface waters in California which had at any time since 1975 exceeded the drinking water standards for nitrate. It would appear that very few streams in northern California have ever exceeded these standards. More streams, though still relatively few in number, have exceeded this standard in the southern half of the State. The more important of these are the Santa Ana River and the Los Angeles River in the Los Angeles Basin, the Santa Margareta River in San Diego County, the Salinas River in Monterey County, the Santa Clara River in Ventura County, and the Chowchilla River in Madera County. While most or all of these rivers are sources of recharge to the ground water body, and thereby ultimately affect the drinking water source, it is doubtful if any are utilized as direct sources of drinking water.

   The sources of excessive nitrate in surface streams can be commonly attributed to one or more of the following: 1) effluent from sewage treatment plants; 2) agricultural effluent runoff, either from surface or from underground drain systems; 3) the stream receiving exfiltration from a high nitrate content ground water body; and 4) industrial and municipal runoff.

2. Nitrate in Ground Water: The major sources of the nitrate found in California's ground water drinking water supply are generally accepted to be the following: leachate produced from agricultural activities and animal and poultry wastes, individual septic tank waste disposal systems, effluent from sewage treatment plants, and municipal and industrial runoff and effluent. Several areas in the State where the soil and water have natural high nitrate contents are known but these are of minor importance as sources of drinking water. In nearly all areas of the State where drinking water contains nitrate above State MCL, the cause may be attributed to one or more of the above human activities.

   a. Agricultural Activities - The largest sources of nitrate in California ground water are those related to agricultural activities, in particular those which utilize the application of nitrogen fertilizers in one form or another. The dilemma which confronts the general public and governmental agencies is that public health concerns would be best served with little or no nitrogen in the drinking water source (of which the largest percentage is ground water), and that the farmer is best served by applying an adequate supply of nitrogen to his growing crops with some unavoidable leachate percolation carrying nitrogen as nitrate to the ground water body. In some areas, nitrate has accumulated in the ground water to the degree that farmers reportedly no longer need apply fertilizer to satisfy crop needs. Meanwhile, these same waters have been competing as drinking water sources in the municipal domain and can no longer meet State drinking water standards. Nearly all ground water basins in the central and coastal parts of California have this competing demand on ground water supplies.

The consumption of fertilizers dramatically increased after 1950 as did the number of acres of productive farmland. California use of fertilizer (nitrogen) rose from 342,142 tons in 1965 to a high of 631,065 tons in 1980 (a figure which is similar to the nationwide use in 1945), since which fertilizer use has more or less stabilized. It has been estimated that about 35 percent of this applied nitrogen is removed by leaching and runoff, the larger portion by leaching downward into the ground water body. Since nitrate ions (NO_3^-) have a negative charge they are not attracted to the soil particles which also have a negative charge. Accordingly, nitrate is both extremely mobile in downward percolating water and exhibits little change in the ground water body. Research has shown that marked changes in fertilizer application rates at the surface may require up to 60 years for the soil leachate to reach and affect the ground water body, implying that worse conditions than now exist may be yet to come.

The production and infiltration of nitrogen leachate is also associated with variables other than fertilizer application rates. These include the agricultural product and its utilization of nitrogen (i.e., citrus, cotton, alfalfa), soil types (i.e., sand, clay loam), permeability, irrigation practices, and others such as subsurface soil organic content. Research which considers these variables shows that not unexpectedly the highest potential for subsurface transfer to the ground water of surface applied nitrogen will occur in high permeability loose sandy soils of low organic content with heavy irrigation. Conversely, should intermittent low permeability layers exist near the surface in sandy soils, denitrification might occur and little nitrate reach the ground water body.

A Master of Science Thesis in Environmental Management from the University of San Francisco summarized statewide ground water and crop data from 238 wells with confirmed nitrate contamination to produce a cursory ranking of which agricultural activities appeared to produce the highest nitrate in ground water. The results were as follows, listing first the activity, followed by the average ground water nitrate value in parenthesis:

Seed Production(104 mg/l)
Greenhouses(103 mg/l)
Vegetable Crops(98 mg/l)
Dairies/Feedlots(93 mg/l)
Vineyards(74 mg/l)
Orchards(73 mg/l)
Fruit Crops(72 mg/l)

Similar data has been produced by others with somewhat comparable results.

The practice of over-irrigation is equally a factor in the production of nitrate bearing leachate moving downward to the ground water body. The reduction of excess applied water would correspondingly reduce the water available for transport of nitrate.

b. Dairy, Feedlot, and Poultry Wastes - Agriculturally related activities such as confined animal facilities, dairies, and poultry/turkey ranches are also large contributors of nitrate to the ground water body. For example, animal wastes, wash water, and runoff from dairy facilities have been strongly implicated as the major contributor to the degradation of the Chino ground water basin in southern California and the Hilmar area in the San Joaquin Valley among others. A recent study by the USDA Soil Conservation Service states that past impacts on the Chino study area of 27,500 acres by the dairy industry have increased NO_3-N from six to 16 mg/l (nitrate 26.4-70.4 mg/l) between 1969 and 1986. It further states that since dairying was begun in the area, ground water quality has degraded from acceptable levels in 100 percent of the wells to only 60 percent of the tested wells meeting drinking water standards, and that if the present rates of degradation continue, within about 25 to 30 years none of the ground water in the study area presently tapped by wells will meet drinking water standards because of nitrate.

Poultry ranch wastes, which accumulated prior to urbanization in the Petaluma area, were held responsible for the high nitrate values in the ground water body which later led to an incident of infant methemoglobinemia.

c. Septic Disposal Systems - About 25 percent of the U.S. population lives in areas where septic tank disposal systems are the norm, and it is estimated that these figures are also relatively true for California. It has been estimated that nationwide about 6 percent of the nitrogen pollution occurs through the use of these waste disposal systems. For practical purposes, a large part of the nitrogen entering a septic tank system is delivered to the ground water body. This is of little significance in sparsely populated areas, but becomes relatively important with the resulting increase in density of such systems brought about by urbanization.

   Effluent from such systems has been estimated to contain up to 70 mg/l of nitrate and/or ammonium nitrogen. In areas where the natural treatment capacity of the soil may be overwhelmed because of high water tables, insufficient treatment area or lot sizes, or sheer numbers of systems, this effluent entering the ground water body will nearly inevitably lead to pollution.

d. Urban Runoff - The nitrate loading of urban runoff has been estimated to be about one-half or less than that from agricultural lands. Lawn and garden fertilizers, pet excreta, leaves, litter, and fallout of soil particles all form varying patterns which make prediction difficult.

e. Municipal Waste Treatment - On a national scale, municipal sewage treatment is not a large part of the nitrogen input to waters, but locally where the surface or ground water body is already overloaded with nitrogen, it can be very important as in the Santa Ana River in Riverside County.

   At best, a conventional primary-secondary treatment plant achieves not more than 30 to 40 percent nitrogen removal. Advanced EPA demonstration plants indicate that nitrogen removal percentages of 90 to 95 are feasible.

CHAPTER IV
EVALUATION OF EXISTING PROGRAMS

A. Resource Identification

1. Current Programs Addressing Nitrate: There are no current ongoing programs that specifically address the causes and the areal extent of the statewide occurrence of nitrate in drinking water. Mandatory sampling programs which are regulated by the DHS monitor violations of the standards for nitrate in drinking water for public water systems. These programs do not make evaluations of that portion of the ground water body lost for beneficial use as drinking water or of the underlying causes of contamination. No State, Federal, or local program attempts to quantify the volume or the percentage of the ground water which has become contaminated by excessive nitrate and is unsuitable for drinking water purposes. Additionally, no program exists which has attempted to quantify the contribution to nitrate pollution from each of the many various sources. In large part, the lack of programs specifically addressing nitrate problems is caused by the setting of priorities for the competing uses of limited resources.

Some specific programs relating to nitrate contamination are presently being carried out by the Regional Water Quality Control Boards. These include the Merced County Hilmar study by Central Valley Regional Board, the Del Norte County Smith River Plain study by North Coast Regional Board, and the San Bernardino County Victor Valley seepage pit and leachfield study being conducted by the USGS and Lahontan Regional Board (Victorville Branch Office). The scope of Santa Ana Regional Board's efforts include not only an intensive review of the nitrogen waste load allocation for the Santa Ana River using a surface water quality model, but also the calibration and verification of a ground water quality model for nitrate. None of the above programs are directed to quantify nitrate problems outside their specific area of investigation.

The DHS monitoring programs of public water supplies may be the largest single source of in-coming data of which nitrate analyses are a part. The use of this program to quantify nitrate problems is misleading, however, for two reasons.

First, in reporting only violations, it assumes no problem exists if there is no violation. For example, a public water supply well may exhibit a violation of nitrate standards for a number of sample periods. As a remedial action, the owners may deepen the well or relocate the supply well and further sampling periods show no violations for that water system. For the DHS program there is no further problem at this point. However, the underlying nitrate contamination in the ground water body has not disappeared, but may in fact be growing in significance. This example also applies to the many local health departments whose primary concern is by statute the immediate threat to public health, not the long term threat to ground water quality. Responses to questions from these sources regarding the existence of nitrate contamination are quite often applicable only to the existence of an immediate nitrate problem as perceived by the responder.

Second, the public water systems are checked as per regulations, but the resulting data does not necessarily find its way into DHS' Drinking Water Monitoring Systems data banks. It is estimated that perhaps 50 percent of the pertinent nitrate data may not be recorded. As the DHS monitoring system at present does not transfer its data into the STORET data banks for permanent storage, this lack of available data is also reflected in STORET.

2. <u>Adequacy of Information on Nitrate Problems and Sources in California</u>:

   a. Data Bases - Computerized data bases from which nitrate data can be extracted exist within the State Board, DWR, DHS, USGS, and EPA, as well as the larger local agencies. These data bases do not all have access to the same input and therefore comparisons of data derived from each varies widely. The results of any nitrate survey will depend upon which data base is entered. For example, a printout received from EPA Regional Headquarters showed no nitrate violations in Kern County during 1986, a STORET printout for the same year shows two violations, and yet 16 such systems applied to DHS for financial aid because they were in violation of State nitrate standards in 1986. The Kern County Environmental Health Department listed 19 small systems as being in violation this same year.

   b. Special Investigations - In general, the results of State-sponsored special investigations of nitrate problems are probably more readily available to local groups than are locally sponsored investigational results to all concerned State groups. Research for this report found that many local health departments, flood control districts, water districts, and others often held data that apparently was not available elsewhere. For any thorough nitrate investigation it will be imperative that close contact is maintained with local agencies.

c. Monitoring Programs - Data from ongoing Federal and State ground water quality monitoring programs are available. These programs, as is stated earlier in this report, are generally not oriented toward defining the limits of specific contaminants such as nitrate. The concentration of effort is more toward defining the overall status of ground water within the State or toward identification of a specific contaminant such as pesticides and may not facilitate an evaluation of nitrate.

California studies, as well as nationwide studies, show that nitrate most often exceeds drinking water standards in shallow wells. A nationwide survey with random sampling showed that 68 percent of the samples exceeding the MCL of 45 mg/l were obtained from wells less than 100 feet deep. Conversely, USGS reports of the Redlands-Highlands area in southern California show excessive nitrate to depths of 500 feet. Overall, monitoring results of only the deeper agricultural and municipal wells will bias the data toward the non-existance of nitrate pollution. This puts at risk primarily the domestic well user who seldom drills a deeper well than required to fill his needs. The domestic user is also the most vulnerable to exposure of high levels of nitrate in drinking water, for warnings to the general public may not be issued except to those users of public water systems.

This possible monitoring bias toward deeper agricultural wells and the deeper wells of large public water systems may be reflected in the STORET data base. For example, for Merced County the data base shows few examples of ground water exceeding the MCL of 45 mg/l (Figure 2), yet from conversations with the county environmental health director and from data furnished by his department as well as from the Regional Board, many areas exist in Merced County where nitrate concentrations exceed the State MCL of 45 mg/l in shallow ground water.

Another example of data that biases any evaluation is that from widely spaced or incomplete monitoring networks. An example is that of Del Norte County, where no recent well water samples are found in the STORET data base that exceed the State action levels for nitrate, yet data obtained from the Regional Board has numerous examples of domestic ground water samples from beneath the plain bordering the Smith River.

Information garnered from these monitoring programs is valuable in defining the overall ground water condition, however, general ground water quality has been long established in many instances and specialized monitoring programs designed for specific conditions should now be established. An effort to more closely monitor the ground water quality of shallow aquifers in certain areas would be the most useful addition to the monitoring program for future nitrate investigations.

B. Data Gaps

The largest data gap that will be found in any statewide nitrate evaluation will be that of a lack of any centralization of available results. For instance, one of the largest single sources of nitrate data relating specifically to drinking water, the monitoring program of DHS, is incomplete because its mandate specifies only public water systems. Similarly, the STORET data is incomplete without the DHS data. The mandates of each of these systems is different and each serves a different purpose. Most organizations have their own data base to some extent and are willing to share if the user will bear the cost of collecting and organizing the data in formats suitable for their own purpose.

Such data that has been acquired in special studies by State or local organizations, for example, DWR Nitrate Study of the Petaluma Area or the Monterey County Study of the Prunedale area, often fails to get entered into the centralized STORET data base and is therefore lost to any numerical evaluation. Personal interviews with responsible parties in both local and State governmental organizations substantiated this fact.

If published reports are a result of the special studies, knowledge of the existence of such data is more apparent. If, however, no report was contemplated and the data were used only for confirmation purposes as is frequently done, knowledge of such data is generally unknown except for the immediate participants and may become lost within a short time. Some means of insuring that relevant data is incorporated into the STORET data base would be of great value in assisting future research. To facilitate this effort, ready access to the STORET system should be provided on a local level with check systems for verification of local input.

While much work has been done determining the relationship between nitrate input and various human activities such as agriculture, septic tank systems, confined animal facilities, and municipal and industrial runoff, these have not been examined in detail to determine the contribution of each under varying circumstances. Research has also been initiated on best management practices to reduce the use of fertilizer so that maximum crop yield and reduced nitrate in ground water are not incompatible. More needs to be done in this area and on reduction from other sources such as dairy management practices, irrigation practices, urban practices in the use of fertilizer, and the existing waste disposal practices.

CHAPTER V
WORKPLANS TO SOLVE NITRATE PROBLEMS

Introduction to Workplan

The earlier parts of this report identified known areas in California where nitrate in water resources are actual or potential problems. Despite the incompleteness and diverse sources of the current data, a significant number of problems have been identified. The actual or probable sources of these problems include long established agricultural and waste disposal practices that have become a part of our societal lifestyle. To solve nitrate problems, changes must occur in these well established practices. Accomplishing such changes will take time, patience, persistence, and probably economic encouragement. Both voluntary and regulatory tools to accomplish such changes and methodologies of approach to accomplish them are discussed in the workplan which follows.

Some may argue that nitrate problems are being solved where and when they need to be and there is no need for a focus on such problems. For example, DHS records of public water systems may be cited as showing a decline in the number of nitrate violations and therefore the elimination of nitrate problems. This is misleading. In reality, DHS records show improved compliance by public water systems through any number of expensive remedial actions such as drilling a well deeper, drilling a new well, blending with an alternate water supply, buying imported water, etc. Nitrate problems may have in fact increased while the problems have only been avoided by the water purveyors at the expense of their customers. This example not only illustrates how misinterpretation of data may occur, but it also raises the issue of what is the appropriate response to nitrate problems and who should pay the costs of taking appropriate measures?

There are three separate avenues that may be taken in addressing nitrate problems. These may be classified as prevention, remediation, and cleanup. Prevention is the elimination or reduction of the sources of nitrate problems. Prevention is the essential element necessary for the long term solution of nitrate problems. Remediation, for this discussion, includes practices such as those discussed in the above paragraph which are employed to avoid dealing with existing nitrate problems. These practices are somewhat temporary solutions and are driven by the immediate economics and needs of the individual circumstances. Cleanup, on the other hand, includes those activities directed at removing nitrate from the water resource.

The Board believes that an integration of the three aspects mentioned above, prevention, remediation, and cleanup, is necessary to address and solve the nitrate problems in

California. The current remedial approaches taken by water purveyors will, by necessity, be applicable until the problem of nitrate in their water supply has been solved. However, these approaches cannot be relied upon indefinitely as the means of addressing the problem and delivering safe water to the public. Concerns of equity are also present with the current remedial approach because the public water user is paying the cost of these measures; costs which will continue to increase if the source is still adding nitrate to the water supply. Current statutory philosophy is that, where possible, the polluter pays the cost of correcting the pollution, and damages associated with it.

Remedies for the nitrate problem will not be found and actuated over night; it will take many years. Current sources may be reduced or stopped, but nitrate presently stored in the soil profile will continue leaching into the underlying ground water body.

<u>Workplans</u>

The following workplans are designed to address specific areas of concern and the development of actions which should be initiated to define and resolve the problems of nitrate pollution.

a. <u>Area of Concern - There is no single organizational unit in any agency concerned primarily with the collection and evaluation of nitrate data, the evaluation of monitoring systems for suitability of nitrate data collection, or the evaluation of attendant causes of nitrate pollution</u>.

The State Board is prepared, under the authority and responsibility given it by the Water Code, to undertake the development of a Nitrate Assessment Group, charged with the responsibility for remedying the above deficits, coordinating activities between agencies, supervising, contracting, and assigning tasks, and administering and budgeting fiscal affairs among other duties. At present the responsiblities for the collection and storing of nitrate data are so diffuse and fragmented that a single group with that specific responsibility must be created or assigned to the task.

<u>Task 1</u> - Two issues this group must first address are those of an evaluation of the useability and comprehensiveness of existing monitoring data and an evaluation of existing data storage systems (ie: STORET, DHS) for future full input and retrievability. Additionally, the methods to be used in the collection of the scattered data and data entry formats must

be determined. The group will also establish the initial action required for the necessary coordination to work directly with and to disseminate pertinent findings to local agencies.

The estimated resources necessary to accomplish this task are one-fourth of a Personnel Year (PY) for each Regional Board and one-half of a PY for the State Board. Travel expenses are estimated at $5,000.00 total.

Task 2 - The next issue addressed in this workplan will be to establish more reliable and universally accepted knowledge of where nitrate problems are in California. As discussed earlier in this report, different agencies are operating with different data sets , each of which is in itself incomplete because of differing data sources. An example; the STORET data base is generally derived from monitoring programs under the aegis of the DWR, the WRCB, and the USGS, while the data in the DHS Drinking Water Monitoring System is derived from public drinking water systems only. Data is not at present fully shared between the two systems. Using the evaluations of data systems capability established in Task 1, interagency agreements and contracts for the integration or interchange of data from these and other sources will be initiated.

The effort to more conclusively define and present the extent of the nitrate problem on a basin-by-basin or county-by-county basis will also be initiated. This program of areal delineation would begin by utilizing the most easily accessible existing data such as that contained in the DHS monitor system and that in the STORET system, and would be further confirmed and expanded as data from local input are received and verified. Procedures for incorporation of new data and updating of maps will also be established at this time.

The nitrate data base thus established would be most effective if coupled with visual representations which are also adaptable for use in representing additional parameters, such as land use, soil characteristics, well parameters, etc. These data can be aquired through the compilation of existing reports and supplemented as needed by contracts with local organizations. Three solutions appear to be applicable should such additional delineations be desired, the use of draftsmen to produce individual overlays, the use of a computer generated graphic information system (GIS), or the use of maps generated by EPA from the data compiled in STORET.

The draftsmen hand-generated approach would appear to be labor intensive and would present difficulties in accommodating the inflow of new data, but would require little or no additional equipment to initiate the process. In contrast, the second approach with the much more sophisticated GIS technique might require contracting or training, and the utilization of expensive equipment. However, the GIS approach does readily allow updating of all parameters as data collection proceeds and the resulting maps for prioritization purposes would be as up-to-date as the latest entries. The third approach is a combination of the drafting technique and the use of computer generated maps. The EPA STORET data base can generate maps at the desired scale for the surface or ground water parameters ordered. The maps in this report were so generated. With the collection and entry of newly gathered data into the STORET data base, such maps would also be up-to-date. This system, however, does not store such other parameters as land use or soil characteristics. These would have to be drafted at scales corresponding to the STORET output, however, these data change less rapidly and would consequently require less updating.

Regardless of source, such maps would provide a public service by delineating the areas where known nitrate problems exist for local officials, private well owners, and potential new private well owners. No convenient and effective means currently exists for the dissemination of such information.

The resources needed for the data collection tasks include consultants and a student intern workforce for the county-by-county data compilation, and the hardware, software, and permanent staff and supplies to maintain a GIS system if chosen. We estimate two-million dollars for consultants and students for a 30-month work effort, $100,000 for the GIS system equipment, and two-personnel years plus $20,000 for an ongoing GIS system supplies and maintenance.

Task 3 - A review and analysis of the existant monitoring systems in operation should be accomplished to determine if they are representative of well systems that might best collect data on nitrate pollution. As stated earlier, wells which are perforated only below confining layers or which have the upper zones sealed off may not necessarily demonstrate the existance of high nitrate waters, although in fact such may be present at shallower depths.

If the monitoring systems appear to be inadequate to allow definition of high nitrate areas, recommendations may be made for modification of sampling parameters, sampling locations, and/or the installation of new monitoring systems. It is expected that cooperation with other agencies, local and State, will assist in lessening the fiscal and labor impact of this task.

This review is not expected to be a lengthy process and might be accomplished by four student trainees under staff direction in a nine-month time frame. Concurrent with the evaluation of monitor well systems, suggestions will be made as to changes or additions to the network. This effort is expected to cost about $50,000 for contracting and 0.5 PY for State Board staff.

Task 4 - With the aquisition of the data collected in the preceding tasks, a source evaluation can be instigated. The relationship of the parameters as developed in the preceding tasks may be examined and evaluated. These relationships, correlated with the existing source assumptions, should define not only how and why nitrate pollution has occurred, but where it may be likely to occur in the future under given conditions.

Trial measures for prevention, remedial action, or clean-up might be attempted in geographic areas which are representative of differing physical parameters and causal effects. The purpose of these projects would be to evaluate the approaches which might serve as models for future legislation, to educate, and to serve in developing and testing guidelines which can be put to practical use. Three demonstration projects are recommended, with one each generally located in the San Joaquin Valley, the Salinas Valley, and in the southern California basins. Each demonstration project should be carried out by a consultant under the direction of the Nitrate Group staff. It is estimated that the consultants cost for each of the projects would be about $200,000 per year for three years. Staff costs for this phase are estimated to be 2.0 P.Y. for Regional Boards, one P.Y. for the State Board staff, and $15,000 general expenses per year.

b. Area of Concern - Each of the methods associated with rectifing nitrate pollution (prevention, remediation, clean-up), has its own particular set of institutional and economic constraints which may impede their introduction on the scale required to be effective.

Task 5 - The elimination of nitrate problems in California must begin with the preceding steps of areal definition and source identification, but following this, appropriate measures to mitigate the problem must be identified and instituted, or the decision must be made to continue as at present. Any new measures to remedy the problem will mean procedural or lifestyle changes with impact on one group or another. These changes will meet with varying degrees of resistance. For these reasons, the available options for each method must be thoroughly reviewed.

The various alternatives such as direct regulation, taxes, economic incentives or disincentives, and proscribed or voluntary guidelines, must all be carefully considered for their economic and technical feasibility.

Regulation of some of these sources is already partially in effect, for instance, septic tank prohibitions in sensitive areas and local land use restrictions which have been formulated in areas where sewers are not available. Waste discharge requirements are also determined and enforced for surface water discharges at confined animal facilities and municipal treatment plants. Ground water degradation from these same facilities has not always received corresponding consideration even though the regulatory principles are in place; and agriculture remains unregulated regarding the application of fertilizer and the irrigation practices which promote the movement of leachate containing nitrate.

Irrigated Agriculture - All of the regulatory and non-regulatory alternatives must receive equal study and consideration if workable and equitable preventive solutions are to be achieved. As an example, a reduction in the application of fertilizer might be realized by increasing its value in the cost of raising a crop, by limiting its appliction in specific vulnerable areas, or by the special training of applicators and voluntary use of appropriate guidelines. All of these and others must be evaluated and weighed for their effectiveness prior to recommending one specific solution in place of another.

The Nitrate Working Committee which has been organized by DFA to develop criteria for Best Management Practices (BMP) in the application of fertilizer is expected to make positive contributions to the evaluation of preventive methods agriculture might take in this area.

The resolution of the agricultural pollution issue will be a long term process, however there are positive actions that can be taken immediately. Above all, the communications gaps that exist between researchers with the development of new techniques for the reduction of nitrate and the end user, the agricultural producer, must be closed. To this end, informational sessions to pass on knowledge of the extent, causes, threats, and methods of prevention of nitrate pollution is a necessity.

The resources necessary to initiate contracts for the needed preventive evaluations, to reproduce and disseminate guidelines for Best Management Practices, and to initiate educational sessions are estimated to be one personnel year and $200,000. Separate guidelines and educational material relating to fertilizer applications for municipal and home use should be developed by contract. These are estimated to require twelve months to develop and cost an estimated $50,000.

Confined Animal Facilities - Resources will be required to perform evaluations on how to best control nitrate pollution from confined animal facilities. The effects of these facilities are already well documented (i.e., Chino Basin). New methods of control and early assessment must be instituted, which hopefully may be carried out with a minimum of disruption to the operator. The initiation of education, informational sessions, and guidelines may bring about voluntary participation and reduce the need for regulation.

Guidelines for improved operational procedures are being produced by the Department of Food and Agriculature Nitrate Working Committee which could serve as a basis for best management practices the Regional Boards might incorporate into waste discharge requirements. Resources of about one PY and an estimated $150,000 would be needed to convert, reproduce, and distribute these guidelines through informational sessions to the dairy, beef, and poultry industry.

Individual Waste Disposal Systems - Resources should be made available for each Regional Board to assess the need for regulation of development densities in each ground water basin where individual waste disposal systems are proposed. The results of such assessments should be incorporated into the Water Quality Control Basin Plans. It is estimated that such assessments by the Regional Boards will take about 1.5 PY and cost about $150,000 for contracts.

The final part of the workplan should make similar evaluations of remedial and clean-up measures. At present, these measures are nearly always undertaken privately by water districts or large suppliers to satisfy their needs. It may be that State participation will be required to more rapidly and efficiently accomplish solutions and fill the demands of the ever increasing population for safe drinking water supplies.

Workplan Summary

This workplan is divided into three components: the first is to quantify the existing problem and to recognize areas with developing shortages of safe drinking water supplies, the second is to develop approaches and changes in practices that will reduce or eliminate future nitrate problems, and the third is to examine and develop solutions for existing problems if governmental assistance is needed. The flexibility is available for sequential efforts, however, the magnitude and interdependence of the efforts is such that it is recommended the phases be performed concurrently.

Interest in the nationwide nitrate problem has become the focus of surveys, research, and suggested regulation by numerous federal agencies. The federal research activities will hopefully be of assistance in formulating preventive and remedial actions. Federal activities and the activities of most other states have focused on the relationships and effects of agriculture on nitrate pollution as having the largest impact. While it is generally recognized by professionals that the activities having the greatest nitrate impact are agriculture, confined animal facilities, and septic systems, by no means should other sources be dismissed. Nitrate sources such as urban run-off, fertilizer related industrial activities, golf courses, horticulture and greenbelt sites, and the effects of improperly abandoned wells must not be ignored in the analysis of institutional and technically feasible solutions.

Summary of Estimated Resource Needs

Task 1 Preparation

- o Prepare Final Workplans
- o Initiate Organizational Contacts
- o Review Options and Select Data Collection Methods
- o Select Data Storage Methods

Fiscal Needs - Regional Boards - 2.25 PY
State Board - 0.50 PY
Expenses - $5000

Task 2 Data Collection and Evaluation

- o Issue Contracts for Nitrate Data Collection
- o Initiate Nitrate Data Storage Plans
- o Issue Contracts for Collection of Land Use Data, Soil Data, and Other Pertinent Data
- o Correlation and Evaluation of All Data with Nitrate Problem Areas

Fiscal Needs - State Board - 2.00 PY
Equipment/Expenses - $120,000
Consultants/Students - $2,000,000

Task 3 Review of Ground Water Monitor Systems for Nitrate Data Collection

- o Review and evaluation of existing systems
- o Review deficits in existing systems
- o Propose modifications or new systems

Fiscal Needs - State Board - 0.5 PY
Contracts - $50,000

Task 4 Assessment of Nitrate Sources

- o Examine Relationships Developed in Task 2
- o Develop Source Priorities
- o Develop Areal Priorities
- o Initiate Demonstration Projects

Fiscal Needs - Regional Boards - 2.0 PY
State Board - 1.0 PY
Expenses - $45,000
Consultants - $1,800,000

<u>Task 5</u> Recommendations for Solutions

- o Propose Appropriate Measures for Priority Areas
- o Initiate BMP and Voluntary Guidelines
- o Propose Regulatory Actions

Fiscal Needs -	Regional Boards	- 1.5 PY
	State Board	- 2.0 PY
	Contracts	- $550,000

TOTAL RESOURCE NEEDS

Regional Boards	5.75 Personnel Years
State Board	6.0 Personnel Years
Consultants/ Contracts	$4,400,000
Expenses	$ 170,000

REFERENCES

Aqua Resources Incorporated, 1985, "Determination of Nitrate Sources in Ground Water with Stable Nitrogen Isotope - Greater Chico Area, Butte County, California."

"The Aquifer: The Journal of the Nebraska Groundwater Foundation," 1987, Volume III, No. 1.

Assembly Office of Research, 1985, "The Leaching Fields, A Non-point Threat to Groundwater," Assembly California Legislature.

Boyle Engineering Corporation, 1985, "Research on Recycling and Recovery of Waste Brines From Nitrate Removal Plants," prepared for McFarland Mutual Water Company.

Bureau of Sanitary Engineering, 1963, "Occurrence of Nitrate in Ground Water Supplies in Southern California," California Department of Public Health.

Burmaster, D.E. and Myers, J.C., 1986, "The Effect of Groundwater Quality on Groundwater Use and Supply," Volume I and II, prepared for Edison Electric Institute, Washington, D.C.

California Department of Food and Agriculture, 1986, "Fertilizer Materials, Tonnage Report."

California Department of Water Resources, 1987, "Antelope Ground Water Study."

-----, 1968, "Delano Nitrate Investigation," Bulletin 143-6.

-----, 1950-1969, "Nitrates in Ground Waters of the San Joaquin Valley," Maps.

-----, 1970, "Nitrates in Ground Waters of the San Joaquin Valley," Memorandum Report.

-----, 1982, "Nitrates in Ground Water, Petaluma Area, Sonoma County," Central District Study.

-----, Order No. WQ 85-1.

-----, 1984, "Study of Nitrates in Ground Water of the Chico Area, Butte County."

California State Water Resources Control Board, 1986, "1986 Water Quality Assessment for Water Years 1984 and 1985," Water Quality Monitoring Report No. 86-SWQ, Section 305(b).

-----, 1963, "Water Quality Criteria, 2nd Edition," The Resource Agency of California.

-----, 1984, "Water Quality Inventory for Water Years 1982 and 1983," Water Quality Monitoring Report No. 84-3TS.

California University Agricultural Exp. Station, 1973, "Nitrates in the Upper Santa Ana River Basin in Relation to Groundwater Pollution," Bulletin 861.

Canter, L.W. and Knox, R.C., 1985, "Septic Tank System Effects on Ground Water Quality," Lewis Publishers, Inc., Chelsea, MI.

----- and others, 1987, "Ground Water Quality Protection," Lewis Publishers, Inc., 121 S. Main Street, Chelsea, MI.

Central Valley Regional Water Quality Control Board, 1983, "Farming and Water Quality: A Handbook for the San Joaquin River Basin."

City of Chico, Butte County, 1985, "Nitrate Action Plan Greater Chico Urban Area."

Dairy Biomass Project, "Evaluation of Dairy Biomass as a Feed Ingredient and for Land Application," Technical Report Number 1.

DMJM/Lowry and Associates, 1978, "Areawide Water Quality Management Plan, San Diego-Riverside Designated Area, Water Quality Problems and Management Responsibilities, Part III Salt Balance," prepared for Comprehensive Planning Organization of the San Diego Region.

Eccles, L.A., and Bradford, W.L., 1977, "Distribution of Nitrate in Ground Water, Redlands, California," United States Geological Survey Water-Resources Investigations Report 76-117.

Eccles, L.A. and Klein, J.M., 1978 "Distribution of Dissolved Nitrate and Fluoride in Ground Water, Highland-East Highlands, San Bernardino County, California," United States Geological Survey Water-Resources Investigations 78-14.

European Chemical Industry Ecology and Toxicology Centre (ECETOC), 1988, "Nitrates and Drinking Water," Technical Report No. 27.

Fogelman, R.P., 1983, "Ground-Water Quality in the Sacramento Valley, California -- Water Types and Potential Nitrate and Boron Problem Areas," United States Geological Survey Hydrologic Investigations Atlas HA-651, 1 sheet.

Fresno County, 1986, "Water Resources Management Plan for Fresno-Clovis Urban and Northeast Fresno County."

Griner, Carol A. and Antilla, Peter W., 1987, "Activities of the Water Resources Division California District in the 1986 Fiscal Year," United States Department of the Interior, Geological Survey, Open-File Report 87-236.

Groundwater Pollutant Study Review Committee in Cooperation with Kern County Health Department, Division of Environmental Health and Kern County Water Agency, 1982, "Groundwater Quality Report San Joaquin Valley, Kern County, California."

H. Esmaili and Associates, Inc., 1978, "Nonpoint Sources of Groundwater Pollution in Santa Cruz and Monterey Counties, California."

Health and Environmental Network, 1988, "Nitrate: Rerun of An Old Horror," Health and Environmental Digest, Volume 1, No. 12

Hurlburt, Scott, 1988, "The Problem with Nitrates," Water Well Journal.

Institute of Water Research, 1972, "Control of Nitrate Contamination," Michigan State University.

Kern County Health Department, 1980, "Ground Water Pollutant Study, San Joaquin Valley Basin, Kern County, California."

Klein, J.M. and Bradford, W.L., 1979, "Distribution of Nitrate and Related Nitrogen Species in the Unsaturated Zone, Redlands and Vicinity, San Bernardino County, California," United States Geological Survey Water-Resources Investigations 79-60.

-----, 1980 "Distribution of Nitrate in the Unsaturated Zone, Highland-East Highlands Area, San Bernardino County, California," United States Geological Survey Water-Resources Investigations 80-48.

Lamb, Charles E. and Woodard, Richard, 1987, "California Ground-Water Quality," United States Department of the Interior, United States Geological Survey, Open-File Report 87-0715.

Metropolitan Water District of Southern California, 1988 "Chino Basin Groundwater Storage Program, Draft Environmental Impact Report," Report No. 975.

-----, 1987, "Groundwater Quality and its Impact on Water Supply in the Metropolitan Water District Service Area," Report No. 969.

National Research Council, 1977, "Drinking Water and Health," National Academy of Sciences.

-----, 1978, "Nitrates: An Environmental Assessment," National Academy of Sciences.

National Technical Information Service, 1977, "The Control of Nitrate as a Water Pollutant," United States Department of Commerce, Texas Agricultural Experiment Station, College Station.

Nielsen, Elizabeth G. and Lee, Linda K., 1987, "The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals, a National Perspective," United States Department of Agriculture, Ecomomic Research Services, Agricultural Ecomomic Report No. 576.

Nightingale, H.I., 1972, "Nitrates in Soil and Ground Water Beneath Irrigated and Fertilized Crops," Soil Science, Volume 114, No. 4.

----- and Bianchi, W.C., 1980, "Correlation of Selected Well Water Quality Parameters with Soil and Aquifer Hydrologic Properties," Water Resources Bulletin Volume 16, No. 4.

----- and Bianchi, W.C., 1974, "Groundwater Quality related to Irrigation with Impacted Surface or Local Groundwater," Journal of Environmental Quality, Volume 3, No. 4.

-----and others, 1977, "Northeast Fresno Ground Water Study - A Data Inventory for Detailed Sampling in Areas of Suspected High Nitrates," U.S. Department of Agriculture, Agricultural Research Service, unpublished.

-----, 1970, "Statistical Evaluation of Salinity and Nitrate Content and Trends Beneath Urban and Agricultural Areas, Fresno, California," Ground Water, Volume 8, No. 1.

Office of Appropriate Technology, State of California Governor's Office, Office of Planning and Research, 1977, "Rural Wastewater Disposal Alternatives Final Report-Phase I," prepared for The California State Water Resources Control Board.

Perrin, H.J., Sr., 1985, "Comprehensive Determination of Primary Chemical Contamination in Small Public Water Systems," M.S. thesis, University of San Francisco.

Polta, R.C. and Wetzel, M.C., 1972, "Control of Nitrate Contamination of Ground Water Associated with Land Disposal of Municipal Sewage," Civil Engineering Department, Michigan Technological Institute.

Pratt, P.F. and others, 1979, "Nitrates in Effluent from Irrigated Lands," Final Report to National Science Foundation, University of California.

Proceedings, Oct 1987, "Agricultural Chemicals and Ground Water Protection: Emergency Management and Policy," St. Paul, Minnesota.

Proceedings, Sept 1985, "The Fifteenth Bienneal Conference on Ground Water," San Diego, California.

Proceedings, Oct 1985, "Plant Nutrient Use and the Environment, a Symposium," The Fertilizer Institute, 1015 18th Street, N.W., Washington, D.C.

Proceedings, Oct 1987, "Review of Water Quality and Agricultural Production," House of Representatives, Committee on Agriculture, Washington, D.C.

Rector, Michael R. and Core, Florn, 1979, "Groundwater Quality Investigation, West Bakersfield-Rosedale Area, Kern County, California," Kern County Water Agency.

Rible, J.M., and others, 1974, "Nitrate in Effluents from Irrigated Lands: Nitrate Concentrations in the Unsaturated Zone Beneath Irrigated Lands," The Kearney Foundation of Soil Science, University of California, Annual Report to the National Science Foundation.

Roy F. Weston, Inc., 1987, "Natural Quality of Groundwater in the United States Compared to Drinking Water Standards," prepared for Edison Electric Institute, Washington, D.C.

Royal Society Study Group, The Royal Society, 1983, "The Nitrogen Cycle of the United Kingdom."

Schmidt, K.D., 1972, "Nitrate in Ground Water of Fresno - Clovis Metropolitan Area, California," Ground Water, Volume 10, No. 1.

Snow, Jerry, and others, 1988, "Nitrates In Ground Water, Salinas Valley California," Monterey County Flood Control and Water Conservation District.

Sposito, Garrison and others, 1987, "Chemical Effects of Saline Drainage Waters on Irrigated San Joaquin Valley Soils," University of California Water Resources Center, Contribution No. 196.

Stout, P.B. and others, 1965, "A Study of the Vertical Movement of Nitrogenous Matter from the Ground Surface to the Water Table in the Vicinity of Grover City and Arroye Grande, San Luis Obispo County," Department of Soils and Plant Nutrition, University of California, Davis, California.

Sullivan, P.J. and others, 1979, "Geological Nitrogen and the Occurrence of High Nitrate Soils in the Western San Joaquin Valley, California," Hilgardia, Volume 47, No. Z.

Swoboda, Allen R., 1977, "The Control of Nitrate as a Water Pollutant," Texas Agricultural Experiment Station.

Templin, William E., 1984, "Ground-Water-Quality Monitoring Network Design for the San Joaquin Valley Ground-Water Basin, California," United States Geological Survey Water-Resources Investigations Report 83-4080.

United States Department of Agriculture, Agricultural Research Service, 1988, "ARS Strategic Groundwater Plan, 1. Pesticides and 2. Nitrates."

United States Department of Agriculture River Basin Planning Staff, Soil Conservation Service, Forest Service, Davis, California, 1988, "Chino Basin Land Treatment Study-San Bernardino and Riverside Counties, California," A Part of California Special Studies Basin and Area Planning, Final Draft.

United States Geological Survey, 1985, "National Water Summary 1984, Hydrologic Events, Selected Water-Quality Trends, and Ground-Water Resources," Water-Supply Paper 2275.

University of California, Division of Agricultural Sciences, 1973, "Survey of Fertilizer Use in California," Bulletin 1887.

University of California, Los Angeles, 1986, "Ground Water Quality in California, A Review of Scientific and Technical Issues," prepared for The California State Water Resources Control Board.

"Water Quality: You're Involved - One Way or Another," 1986, Published by Fertilizer Progress.

Webster, D.A., 1972, "Map Showing Areas in the San Francisco Bay Region Where Nitrate, Boron, and Dissolved solids in Ground Water may Influence Local or Regional Development," United States Geological Survey, Miscellaneous Field Studies Map MF-432.

Wendt, Charles W. and others, 1976, "Effects of Irrigation Methods on Groundwater Pollution by Nitrates and Other Solutes," Texas Agricultural Experiment Station.

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Evaluation of the Nitrate Drinking Water Standard with Reference to Infant Methemoglobinemia and Potential Reproductive Toxicity

ANNA M. FAN,* CALVIN C. WILLHITE, AND STEVEN A. BOOK

Office of Environmental Health Hazard Assessment, California Department of Health Services, 2151 Berkeley Way, Berkeley, California 94704

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In view of published results of epidemiologic studies which suggested an association between nitrate in drinking water and human malformations, an assessment of the toxicology of nitrates and nitrites in relation to possible adverse effects on reproduction and development was performed. The current water standard for nitrate is based on protection from methemoglobinemia. A review of the animal data failed to provide evidence for teratogenic effects attributable to nitrate or nitrite ingestion. Adverse reproductive effects reported occurred at doses that were about one thousand times and higher than the estimated human intake. Neither nitrate nor nitrite in experimental animals concentrated in the mammary gland or milk. The present assessment concludes that the maximum contaminant level of 45 ppm nitrate ion, or 10 ppm nitrate-nitrogen, adequately protects the very young from nitrate-induced toxicity, both pre- and postnatally.

INTRODUCTION

Nitrate in drinking water was first identified with infant methemoglobinemia in 1945 (Comly, 1945). In 1962, the U.S. Public Health Service recommended a maximum permissible level of 45 ppm for nitrate (NO_3^-), or 10 ppm nitrate-nitrogen (NO_3–N), in drinking water (McKee and Wolf, 1963). This level was established from retrospective studies, and it approximates a level below which infant methemoglobinemia would be unlikely. This level corresponds to the current U.S. federal maximum contaminant level (MCL) for drinking water (California Department of Health Services, 1977).

The suggested association between nitrate in drinking water and human neural tube defects by Dorsch *et al.* (1984) and Scragg *et al.* (1982) generated a concern about potential toxicity of nitrates for the developing embryo and for nursing infants.

* To whom correspondence should be sent: Community Toxicology Unit, Office of Environmental Health Hazard Assessment, California Department of Health Services, 2151 Berkeley Way, Berkeley, CA 94704.

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The toxicology of inorganic and organic nitrites and nitrates has been summarized by the NAS (1981) and WHO (1977). The present review considers the pertinent literature, assesses the toxicological significance of nitrates in pregnant and lactating mothers and their offspring, and examines the adequacy of the current federal and California nitrate drinking water standard for protection of these members of the population.

Neural tube malformations are among the most common and most severe congenital malformations that are compatible with intrauterine life. Anencephalus and craniorachischisis totalis are incompatible with extrauterine life, whereas encephalocele and spina bifida with myeloschisis, commonly associated with Arnold–Chiari malformation, can be repaired with some degree of success. Many of these malformations were observed in ancient civilizations. The current total incidence in the United States is 1.0–1.3/1000 conceptions in the United States (Myrianthopoulos, 1979). The incidence of neonatal neural tube defects is increased 10 times (to approximately 40/1000 births in the United Kingdom) among women who have given birth to an affected child, but 95% of affected infants are born to women without such history.

Geographical location, seasonality (time of year at which conception occurs), genetic background, and diet are contributing factors to the incidence of the disease (Elwood and Elwood, 1980; Sever, 1975; Al-Awadi *et al.*, 1984). The prevalence of the disease in the United States is 25–50% of that in the United Kingdom. The incidence decreases in the first and second generations after immigration to the United States. An excess of affected births occurs in winter, and the peak date of conception for spina bifida is two months later than that for anencephalus (Elwood and Elwood, 1980). The incidence of human anencephalus ranges from 0.11/1000 births in Bogota, Colombia (Stevenson *et al.*, 1966), to 0.49/1000 births in Los Angeles (Smilkstein, 1962), and to 5.93/1000 births in Dublin, Ireland (Coffey and Jessop, 1957).

NITRATES AND NITRITES: SOURCE AND EXPOSURE

The nitrate ion is formed from the complete oxidation of ammonia by soil and/or water microorganisms and nitrite is an intermediate product of the oxidation process. Nitrite is also formed from nitrate or ammonium ion by microorganisms in soil, water, sewage, and the digestive tract. The ammonia is generated from degradation of protein and urea and is synthesized during nitrogen fixation. In oxygenated natural waters, nitrite is rapidly oxidized to nitrate. Increased nitrate levels in groundwater or in rural and municipal water supplies usually occur as a result of contamination by human or animal organic waste or from nitrogenous fertilizers (Deeb and Sloan, 1975). Inorganic nitrates are found naturally in carrots, spinach, celery, lettuce, radishes, and beets. Nitrites are used as curing agents and meat preservatives. Sodium nitrite has been used as a vasodilator in doses of 30–120 mg (WHO, 1962), and it is injected intravenously as a cyanide antagonist (Gosselin *et al.*, 1984).

The chief source of the nitrate body burden, excluding consumption of high-nitrate water, is vegetables (NAS, 1978). Other sources include cured meats, fruits, juices, milk and milk products, and breads. Large individual variations exist with respect to the relative importance of different nitrate sources. For nitrite, the major source is saliva. Nitrite is produced in the mouth and pharynx by bacterial reduction of nitrate

TABLE 1

ESTIMATES OF AVERAGE DAILY NITRATE AND NITRITE INGESTION IN THE UNITED STATES (mg/PERSON/DAY)

Nitrate (NO_3)	Nitrite (NO_2)	Reference
	Total, food and water	
99.8[a]	2.6[a]	White (1976a, b)
39.1[b]	0.32[b]	Miller (1980), Hartman (1982)
68.2[c]	0.55[c]	Hartman (1982)
57–64	—	WHO (1977)
—	1.5	Khera (1982)
75[d]	0.77[d]	NAS (1981)
100[d]	0.57[d]	Birdsall (1981)
(268 for vegetarian)	(0.77 for vegetarian)	NAS (1981)
	Water only	
0.186		Hartman (1982)
2.0	0.01	NAS (1981)
(2.0 for vegetarian)	(0.01 for vegetarian)	NAS (1981)

[a] Based on estimated content times production figures for various products, with loss before consumption subtracted; including 0.7 mg from water.
[b] Based on food-consumption data for vegetables, water, and cured meat.
[c] Based on food-consumption data, water included.
[d] Water included.

in ductal saliva. The exposure is at a continuous low level, as contrasted with the short-term exposure received from ingestion of a bolus dose of cured meat. The estimates of daily nitrate and nitrite ingestion per capita in the United States are summarized in Table 1.

Nitrates per se are not toxic at the levels normally present in foods. Inorganic nitrates added to meats have no specific pharmacologic actions. Sodium and potassium nitrate resemble sodium chloride in their physiochemical effects (Association of Food and Drug Officials of the United States, 1979). The toxicity of ingested nitrate is due to its *in vivo* reduction to nitrite and the subsequent methemoglobinemia. The chemical species and route of nitrite exposure determine the circulating methemoglobin (metHb) concentrations; the net concentration represents nitrite oxidation of hemoglobin and metHb reduction catalyzed by erythrocyte diaphorase (methemoglobin reductase) (Smith, 1980). The Joint Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) Expert Committee on Food Additives estimated the acceptable daily nitrate ($NaNO_3$) intake for man to be 0–5 (unconditional acceptance) and 5–10 (conditional acceptance) mg/kg (WHO, 1962). Levels of 0–0.4 and 0.4–0.8 mg/kg nitrite ($NaNO_2$) were assigned ratings of unconditional acceptance and conditional acceptance, respectively. These levels, however, were not applicable to infants under 6 months of age, who are more susceptible to methemoglobinemia.

Nitrates also occur as inorganic aerosols and in the organic products of photochemical smog (NAS, 1978). The predominant form in urban air is peroxyacetyl nitrate and in rural air nitric acid and nitrate salts predominate. If one assumes total retention of inhaled nitrates, an adult living in Los Angeles can be calculated to receive a daily dose of approximately 500 μg nitrate–nitrogen (150 μg inorganic nitrate, 4000 μg peroxyacetyl nitrate, and 120 μg alkyl nitrate).

Municipal drinking waters in the United States seldom exceed 10 mg NO_3–N per liter (NAS, 1978). Private well water is more often the source of high nitrate exposure, especially that from shallow wells with depths less than 15 m in regions with impermeable soils. The contribution of nitrate in drinking water was estimated in 1972 to account for 0.7% of the total average daily dose or 0.062 mg/person per day (White, 1976a,b). An estimate of 0.186 mg/person per day from drinking water was made for 1978 (Hartman, 1982).

METHEMOGLOBINEMIA AND INDIVIDUAL SUSCEPTIBILITY

Methemoglobinemia is the most prevalent and potentially the most serious complication of nontherapeutic, excessive nitrate and nitrite exposure. Nitrate in drinking water is the most common factor associated with clinical methemoglobinemia. The condition is characterized by cyanosis, stupor, and cerebral anoxia. Nitrite directly oxidizes the hemoglobin ferrous iron (Fe^{2+}) to the ferric state (Fe^{3+}) which cannot bind oxygen. Reduced oxygen transport produces tissue hypoxia. Approximately 1% of adult hemoglobin normally circulates as metHb; in children less than 2% of the total hemoglobin circulates as metHb. Signs of methemoglobinemia appear at levels of 10–20% metHb, and death occurs at levels of 60% or higher (NAS, 1981).

Consumption of high-nitrate water causes infant methemoglobinemia much more frequently than in adults. The greater susceptibility of infants can be attributed to several factors (NAS, 1981), including the greater total fluid intake per unit body weight, consumption of larger amounts of nitrate relative to the total hemoglobin for a given nitrate concentration in water (Lachhein *et al.*, 1960), and a diminished capability to secrete gastric acid in the infant which permits a rise in upper gastrointestinal tract pH to 5–7, allowing bacterial proliferation and nitrate catalysis to nitrite. Similarly, infant gastroenteritis may favor the development of metHb when the upper gastrointestinal tract becomes colonized with bacteria.

Other contributory factors include a transient deficiency in metHb reductase or its cofactor, reduced nicotinamide adenine dinucleotide (NADH) in infants, and the greater susceptibility of hemoglobin F (fetal hemoglobin) to oxidation than hemoglobin A (adult hemoglobin). At birth, 60–80% of the circulating hemoglobin is composed of hemoglobin F, but this value decreases to approximately 30% by the third month of life (NAS, 1981; Winton *et al.*, 1971).

In addition to infants, other individuals are predisposed to nitrite- (or nitrate)-precipitated methemoglobinemia. Altered physiologic states, dietary parameters, and hereditary or acquired disease can increase individual variations (NAS, 1981). Examples include pregnant women and individuals with glucose-6-phosphate dehydrogenase deficiency, achlorhydrosis (including those treated for peptic ulcer and those with chronic gastritis or pernicious anemia), and hereditary deficiencies of erythrocytic methemoglobin reductase or NADH. Additional groups include those with hemoglobinopathies such as hemoglobin Ms., in which variations in the amino acid residues create new, strong bonds with the heme iron, maintaining it in the ferric state. High dietary ascorbate levels decrease metHb formation and enhance its reduction to hemoglobin (Shearer *et al.*, 1972; Shuval and Gruener, 1972). Individual cooking habits contribute to nitrate exposure, as simmering or repeatedly boiling water can increase nitrate concentrations (Shuval and Gruener, 1974). Dialysis patients are uniquely susceptible to methemoglobinemia; methemoglobinemia with cyanosis, hypotension, and nausea has been associated with a concentration of 21 mg nitrate–nitrogen per liter in the dialysate (Carlsen and Shapiro, 1970). A water standard of 2 ppm nitrate in water used for hemodialysis has been recommended (Keshaviah and Luehmann, 1981).

METHEMOGLOBINEMIA MORBIDITY AND MORTALITY

From 1945 to 1970, approximately 2000 cases of infant methemoglobinemia were reported. Fatality rates averaged 8% (Fraser and Chilvers, 1981). More than 80% of the cases involving known water nitrate contamination were associated with concentrations greater than 100 ppm (Walton, 1951; Winton *et al.*, 1971; Simon *et al.*, 1964). Three percent of the cases compiled from 14 countries were associated with water nitrate concentrations less than 40 ppm (Winton *et al.*, 1971). The contribution of nitrate-containing water was unknown in 32–67% of the cases reviewed by Walton (1951), but no cases were reported in the United States where the water nitrate levels were less than 50 ppm. Simon *et al.* (1964) found that 4.4% of the German cases occurred in areas with water nitrate levels less than 50 ppm.

More recent cases of human methemoglobinemia reported in the United States involved an infant ingesting municipal water containing 13.3 ppm NO_3–N in Colorado (Virgil *et al.*, 1965), infants ingesting well water with 17.1 ppm NO_3–N in Texas or 24.4 ppm NO_3–N in Oklahoma (Jones *et al.*, 1973), and an adult using home dialysis with water from a private well containing 92.7 ppm NO_3–N (Carlson and Shapiro, 1970).

Winton *et al.* (1971) studied 111 infants of ages less than 2 weeks to 6 months in Southern California and Central Illinois and found the nitrate (NO_3^-) doses from water to be 1 mg/kg for 63 infants, 1.0–4.9 mg/kg for 23 infants, 5.0–9.9 mg/kg for 20 infants, and 10.0–15.5 mg/kg for five infants. The mean normal circulating metHb level was 1.6% compared to a normal range of 1.0–2.9%. The highest metHb level found was 5.3%. None of the infants showed signs of methemoglobinemia. The circulating metHb levels returned to normal when the infants subsequently drank low-nitrate water. Shuval and Gruener (1977) found a significant increase in circulating metHb in infants drinking water containing 45–55 ppm nitrate, but no cases of clinical methemoglobinemia. Soviet studies reported elevated metHb in schoolchildren drinking water containing 204 (Diskalenko, 1968) or 23 ppm (Subbotin, 1961) NO_3–N. Craun *et al.* (1981) failed to observe elevated metHb concentrations in Illinois children aged 1–8 years who drank water containing 22–111 ppm NO_3–N.

In spite of shortcomings in clinical diagnosis and water analyses in some of the above studies, one consistent observation was the absence of clinical metHb in populations whose drinking water NO_3–N concentrations were less than 10 ppm (NAS, 1981). Only 2.3% of the cases were infants associated with water concentrations of 10–20 ppm NO_3–N.

Infant metHb also results after absorption of aniline derivatives found in certain diaper marking dyes, shoe polish, wax crayons, and disinfectants (Jones *et al.*, 1973).

In addition, metHb concentrations increase after ingestion of canned foods with high nitrite content. In all cases of food-borne nitrite intoxication, the levels were greatly in excess of the maximum permitted residue level of 200 ppm (NAS, 1981).

PRESENCE IN MILK

Many authors consider human or bovine milk as unlikely sources of infant methemoglobinemia. Davidson (1964) found little nitrate in the milk of cows drinking water containing 800 ppm nitrate. However, Donahoe (1949) reported one case of a breast-fed infant with clinical metHb who returned to normal after the mother was instructed to drink neither the water from the farm well nor milk from cows consuming farm water. No information was given about nitrate in the well. Donahoe (1949) also reported a case of infant metHb whose formula contained milk from cows drinking water with 177 ppm nitrate. Simon *et al.* (1964) reported that bovine milk contains 0–0.5 ppm nitrate. Human milk is not nitrate-enriched (Hartman, 1982) and neither the human, rodent, nor canine mammary gland concentrates nitrates. When lactating beagle dogs were given an intravenous injection of 10 mg/kg sodium nitrate, the nitrate concentration in milk rose to 8.7 ppm at 6 hr after injection and was undetectable at 48 hr (Green *et al.*, 1982). The blood nitrate was 15 ppm at 1 hr after injection and plateaued at 1.2 ppm from 48–96 hr after injection. Milk and saliva from lactating women collected 1 hr after the normal evening meal contained milk nitrate concentrations no higher than those found in plasma (1.0 ppb). Salivary nitrate concentration was greater (10–15 ppb) than that in plasma (Green *et al.*, 1982). Gruener and Shuval (1970) found that 3 ppm sodium nitrate in the drinking water of lactating rats induced maternal metHb, but failed to produce elevated metHb in the suckling young. These authors concluded that nitrite was not transferred in appreciable amounts to the pups via milk.

REPRODUCTIVE AND DEVELOPMENTAL TOXICOLOGY

Although increased rates of abortion in farm animals ingesting hay containing high levels of nitrate have been suggested, Davidson (1964) and Simon *et al.* (1964) concluded that chronic nitrate exposures exerted no significant abortifacient effects on ewes or heifers at levels approaching those that induce methemoglobinemia. Deeb and Sloan (1975) discussed anecdotal reports of Missouri workers who suspected that abortions occurred in apparently disease-free cattle after consumption of forage containing 1% potassium nitrate and reports of nonspecific abortions in Wisconsin cattle grazing on nitrate-containing plants. In addition, abortion occurred in three cows given 100 g potassium nitrate (14 g NO_3–N) by rumen fistula, in one cow fed 100 mg NO_3–N/kg/day, in two cows fed 150 mg NO_3–N/kg/day (45 heifers were studied, and the treatment period was variable), and in three of seven ewes fed forage containing 3.4% nitrate. No such effects on pregnancy were observed in heifers fed a balanced ration containing sufficient sodium nitrite or sodium nitrate to maintain a 20–50% level of maternal MetHb, in cows fed potassium nitrate-supplemented corn silage or oats containing up to 2.3% nitrate (0.52% NO_3–N), in ewes fed oats containing 0.8% potassium nitrate (0.11% NO_3–N), in sheep fed a ration containing 1.5% potassium nitrate (0.21% NO_3–N) during the latter part of pregnancy, or in swine fed diets containing 300 ppm nitrate nitrogen and 100 ppm nitrite nitrogen (Deeb and Sloan, 1975).

Shuval and Gruener (1974) pointed out that the lack of agreement on the toxic dose of nitrate/nitrite for livestock stemmed from differences in the method of exposure, the age and nutritional status of the animal, and the conditions under which exposure occurred. Growth inhibition and poor performance in livestock and poultry were often associated with either reduced consumption of feed or water, the nitrate content of which was sufficient to reduce palatability, or with nitrite-induced vitamin A deficiency (Deeb and Sloan, 1975). The abortions in dairy cows and in ewes occurred under conditions that resulted in fatal methemoglobinemia in some of the animals (Emerick, 1974).

Preliminary studies in laboratory animals have also considered nitrites in pregnancy. Gruener and Shuval (1970) provided drinking water with 300 ppm sodium nitrite to pregnant rats (number not specified) during the last week of pregnancy and to 3 weeks after parturition. Newborns exhibited 5–10% metHb, whereas dams had levels of 45%. After a few days, the suckling rats had normal metHb concentrations, but the mothers exhibited elevated metHb. The control and treated birth weights were comparable, but after 3 weeks decreased weight gain and survival occurred in the pups suckling nitrite-exposed mothers. Therefore, increased newborn mortality and decreased weight gain were not associated with neonatal metHb. Shuval and Gruener (1971, 1972) exposed groups of 12 pregnant rats to 2000 or 3000 ppm sodium nitrite in drinking water. Maternal treatment continued from parturition until weaning. A dose-related maternal anemia occurred, but no significant elevation in circulating metHb in the young was found. Increased neonatal mortality, decreased weight gain, and alopecia were observed.

Sleight and Atallah (1968) administered potassium nitrate to groups of three to six female guinea pigs for varying periods at a concentration of 0, 300, 2500, 10,000, or 30,000 ppm in water. The equivalent daily doses were 0, 12, 102, 507, and 1130 mg/kg/day of nitrate–nitrogen, respectively. Duration of exposure varied from 143 to 204 days. Numbers of litters and live births decreased at 30,000 ppm, with reproductive performance being only 8% of that of the controls. The highest dose group had mummified or absorbed fetuses and the highest percentage of fetal loss. The lowest dose group had the second highest rate of fetal loss, due mainly to still birth. No dose-related trend was seen. Potassium nitrite at 0, 300, 1000, 2000, 3000, 4000, 5000, and 10,000 ppm in water was also given to groups of three to six guinea pigs for various periods. Equivalent daily doses were 0, 18, 45, 154, 182, 192, 244, and 577 mg/kg nitrite–nitrogen for a period of 100 to 240 days. There were no live births at the two highest levels compared to 31 in the controls. Lower levels showed varying degrees of fetal loss and litter size, with mummified or absorbed fetuses seen at 4000 and 5000 ppm. Abortion occurred at the two highest levels. Degenerative placental lesions and inflammatory uterine and cervical lesions were present in females in which the fetuses had died. The numbers of animals used were small; the period of treatment in relation to the time of conception and the comparative reproductive success rate were not specified.

Subcutaneous injection of 60 mg/kg of sodium nitrite in guinea pigs during the last trimester induced abortion within 1–4 days (Sinha and Sleight, 1971). An injection of 50 mg/kg failed to induce maternal or fetal toxicity and an injection of 70 mg/kg caused maternal death. The fetal metHb concentration after 60 mg/kg was always less than the maternal metHb concentration and no fetal death occurred after methylene blue antagonism of metHb. The lower PO_2 values in fetuses of treated animals suggested that fetal death resulted from hypoxia secondary to maternal methemoglobinemia.

Dietary administration of sodium nitrite at 0, 0.0125, 0.025, or 0.05% (w/w) to male and female rats for 14 days prior to mating, during breeding, and to the dams during pregnancy and lactation failed to demonstrate significant adverse effects on parental weight gain, food consumption, mortality, fertility, gestation period, litter size, sex distribution, birth weight, or external morphology of the young (Vorhees *et al.*, 1984). A significant increase in neonatal mortality was observed at the highest dose, but no significant effects were observed on postweaning or adult behavior. Anderson *et al.* (1978) provided CD-1 female mice with drinking water containing 1000 ppm sodium nitrite for 10 weeks prior to conception and throughout pregnancy. No consistent changes in litter size, neonatal body weight, or perinatal survival were observed. Heinz *et al.* (1983) reported retardation in the offspring of rats provided with high nitrate doses of greater than 1 g nitrate/kg, a dose more than 1000 times the human acceptable daily intake.

Malestein *et al.* (1980) administered an oral dose of 30 mg/kg sodium nitrate to cattle during parturition and found increased metHb concentrations in both dam and calf, but the increase in metHb was greater in maternal blood than in fetal blood. The authors concluded that possible fetotoxicity associated with maternal sodium nitrite ingestion would be associated with decreased oxygen transport to the placenta secondary to maternal methemoglobinemia, rather than to fetal methemoglobinemia per se.

Shank and Newberne (1976) fed sodium nitrite to two generations of rats and found no effect on litter size, infant mortality, growth rate, or longevity. The diet contained 1000 mg/kg of added sodium nitrite. The concentration of residue after mixing was 240–460 mg/kg of sodium nitrite, or 49–93 mg/kg of nitrite–nitrogen.

Studies on the possible teratogenicity of nitrates and nitrites have been conducted in birds, rats, mice, hamsters, and rabbits. Chicken eggs were injected with a saline solution of sodium nitrate in an attempt to study the pathogenesis of neural tube defects (The, 1982). Although anencephaly (probably exencephaly) and myeloschisis were induced, the results are difficult to extrapolate to humans because the independence of the chick embryo does not allow for maternal toxication or detoxification, and the chemical is placed at high levels directly in contact with the embryo. Apparently no controls were used and no mention of the numbers of chicks or the dose was made.

Khera (1982) found that a single oral dose of 80, 100, or 120 mg/kg sodium nitrite in pregnant rats (strain and source unspecified) administered on Day 13 failed to induce a teratogenic response. A reference teratogen, ethylene thiourea (ETU), induced craniofacial, spine, and limb malformations. At 120 mg/kg, maternal fatalities occurred, but no treatment-related differences were reported in the numbers of live fetuses per litter, embryonic or fetal deaths, or the mean fetal body weight. Neither maternal nor embryonic toxicity was observed at the two lower doses. However, the single-exposure regimen failed to address the entire period of organogenesis and the author failed to determine maternal circulating metHb levels. The results of the study can only be suggestive that no teratogenic or embryolethal effects were associated with maternal sodium nitrite ingestion.

Combined ingestion of ethylurea and sodium nitrate was reported to result in rat fetal malformations which paralleled closely the pattern recorded with *N*-nitrosoethylurea and comprised mainly developmental defects associated with the nervous system (Dreosti *et al.*, 1983). However, the appearance of terata within a treatment group was erratic following the combined treatment, with only some litters being severely affected. Although the data support the notion that dietary nitrate, after reduction to nitrite, may be teratogenic via the formation of nitrosamines within the gastrointestinal tract, the study is limited in that only small numbers of animals were used (3 to 15) and nitrate itself was not shown to be teratogenic.

Globus and Samuel (1978) treated pregnant CD-1 mice from Day 1 to Days 14, 16, or 18 of pregnancy with 0.5 mg/mouse/day of sodium nitrate (or approximately 15 mg/kg per day). No skeletal malformation or adverse effects on embryonic or fetal growth which could be attributed to nitrite treatment were observed. The authors stated that there was some evidence for stimulation of erythropoiesis, but the significance of this observation for postnatal growth and survival was not determined.

In a study on the fetal toxicity of potassium nitrate (Makoto and Seizaburo, 1983), rats were fed a diet containing the chemical at 0, 0.1, 0.5, or 2.5% from Days 7 to 14 of pregnancy. No maternal or fetal toxicity, external malformations, or other harmful effects were observed at term and until 13 weeks after birth of the offspring. Pregnant rats from mating of F_1 males and females were fed the same diet from Days 7 to 14 of pregnancy. The results did not indicate teratogenicity. The F_2 males of the treated groups suggested slow growth until 13 weeks after birth.

Inui *et al.* (1979a) found that sodium nitrite given to pregnant hamsters on Day 11 or 12 gave some indication of "transplacental mutagenesis," but no chromosome changes were reported. Since sodium nitrite treatment occurred well after the critical period for neural fold elevation, apposition, and fusion (Days 7 and 8), the data presented cannot be considered as evidence that nitrite exposure was without developmental toxicity in hamsters. Teramoto and associates (1980) failed to observe terata in sodium nitrite-exposed fetal mice. One study reported that 1% sodium nitrite in rat chow was associated with maternal death, but the investigators found no evidence for embryotoxic or teratogenic effects (Alexandrov and Janisch, 1971).

Studies by the Food and Drug Research Laboratories submitted to the Food and Drug Administration on the evaluation of the teratogenicity of sodium and potassium nitrate and sodium and potassium nitrite did not show any teratogenic response (FDA, 1972a,b,c). Pregnant mice, rats, hamsters, and rabbits were given four levels of each of the chemicals orally. The dose levels for sodium nitrate were up to 400 mg/kg for mice and hamsters and up to 250 mg/kg for rats and rabbits. Potassium nitrate was given at up to 400 mg/kg for mice, 1980 mg/kg for rats, 280 mg/kg for hamsters, and 206 mg/kg for rabbits. There were no effects on nidation, maternal or fetal survival, and incidence of soft or skeletal tissue abnormalities in the treated groups. In these FDA studies, sodium nitrite was given to mice, rats, hamsters, and rabbits at up to 23, 10, 23, and 23 mg/kg, and potassium nitrite was given to the four species at up to 32, 10, 32, and 23 mg/kg, respectively. For both chemicals at the highest dose level of 10 mg/kg given to rats, there was a slight indication of delayed skeletal maturation, especially in the ribs and skull, but no increase in terata. In the hamsters, delayed skeletal maturation was seen, but it was not dose-related.

Super *et al.* (1981) reported increased deaths during infancy in African/Namibian infants born previously to mothers from high nitrate areas. There was, however, no correlation between nitrate area and prematurity and stillbirths. The findings represent a statistical association but there is no evidence of a causal relationship.

The studies of Dorsch *et al.* (1984) and Scragg *et al.* (1982) examined the relationship between the occurrence of human malformations and consumption of groundwater during pregnancy in South Australia. The results provide suggestive evidence for an association between the consumption of groundwater containing high levels of nitrate and congenital malformations. However, the variety of malformation categories reported would argue against the hypothesis that a single factor in the groundwater was causally associated with these anomalies, in which case the effects would be expected to be more specific. In addition, both the contribution of water supply and mother's residence seemed to have a significant effect. The possibility that other unidentified materials or environmental variables may be correlated with the water supply, that other unidentified spatial variables may be independent of water supply, or that other factors associated with both residence and water supply may act as determinants of the malformation risk cannot be excluded. Dorsch *et al.* (1984) indicated that it was difficult to evaluate other alternatives to the groundwater and nitrate hypotheses, given the small samples and limited nature of the data available on the individuals, and that it would be premature to interpret the study exclusively in terms of water nitrate exposure.

SUMMARY AND DISCUSSION

Nitrates are natural constituents of many soils and are found in most growing plants and in water that may be used for drinking. The consideration of permissible intake of nitrate from water must take into account the amount of nitrate ingested from foods. Human health concerns are related to both nitrate and nitrite, because nitrate is converted to nitrite after ingestion.

The intakes of nitrates by members of the general population are difficult to estimate, but the data suggest an ingestion of 39 to 99.8 mg nitrate and 0.32 to 25 mg nitrite per day. A no-observed-effect level of 1% sodium nitrate in the diet, or 500 mg/kg/day, has been determined for rats in a 2-year study (WHO, 1962). Using a safety factor of 100 for the NOEL, this would provide a permissible daily intake of 222 mg nitrate for a 60-kg person, a level which is still higher than the total daily intake of 189.8 mg (the highest estimate of 99.8 mg from food and 90 mg from water at the MCL at a consumption rate of 2 liters per day) even if water consumption provided a maximum daily dose at the MCL of 45 ppm nitrate. Actual intake from water has been estimated to be 0.186 to 2.0 mg/person/day. Vegetarians would have a smaller margin of safety of 62-fold.

The assessment of health risk of nitrates to man has been based primarily on epidemiological studies and clinical incidence of methemoglobinemia. The established standard of 45 ppm nitrate in drinking water appears adequate for protection against methemoglobinemia, but the available information does not permit the establishment of a quantitative dose–response relationship for human exposure to nitrates in water or food. In most epidemiological studies, either the data concerning nitrate or nitrite concentrations in water or food were not reliable enough or the amounts of water or food had not been measured (WHO, 1977). No generalization is possible about the relationship between the nitrate concentration in drinking water and the dose of nitrate, and the nitrate dose from water or food varies according to local conditions and individual dietary habits.

The limited experimental data available do not support the transfer of appreciable amounts of nitrates in milk, although two cases of methemoglobinemia have been reported to be associated with either mother's milk or cow's milk. The latter involved a drinking water concentration of 177 ppm, which was considerably above the MCL, while no determination was made for the former. Therefore, there are no data suggesting appreciable levels in milk resulting from ingestion of nitrate in water at or below the current water standard.

The assessment of potential reproductive toxicity resulting from human exposure to nitrate from drinking water is complicated by the fact that whereas nitrate is the form ingested from food and water, much of the relevant toxicological data available in the published literature concern nitrite. Extrapolation of nitrite toxicity data in animals to nitrate exposure in humans is based on the possible reduction of nitrate to nitrite in the human body. However, not all the nitrate in the body is reduced to nitrite. The extent of reduction of nitrate to nitrite, the rate and the site of absorption from the gastrointestinal tract, the interconversion in the circulatory system, and the body burden are not clearly known. The effects seen in experimental animals given high single dosings of nitrite are difficult to extrapolate to the human situation wherein nitrate ingestion from water is gradual and extended over days, months, or years. At an assumed 5% nitrate to nitrite reduction rate (Spiegelhalder *et al.*, 1976; NAS, 1981; Hartman, 1982), the estimated human daily nitrite dose is about 1000 times and more below the suggested reproductive effect levels reported for nitrite in animals. Therefore, the established MCL appears adequate for protection against these effects. However, the assumption of a 5% physiological conversion of nitrate to nitrite in saliva of normal subjects does not provide a margin of safety for particularly sensitive individuals whose gastrointestinal tract would allow for increased reduction of nitrate to nitrite, although it may help to explain the greater toxicity of ingested nitrite compared to nitrate.

Considering all the reported findings, there is no evidence to show that exposure to nitrate produces adverse reproductive or teratogenic effects. The data show that although nitrite can cross the mammalian placenta and induce fetal metHb after maternal ingestion, there is no evidence to conclude that oral nitrate or nitrite was teratogenic in the species examined. Thus the studies of Dorsch *et al.* (1984) and Scragg *et al.* (1982) provide an interesting hypothesis for possible relationships between drinking water contaminants and human neural tube effects, but the hypothesis cannot be supported by the presently available animal data.

REFERENCES

ALEXANDROV, V. A., AND JANISCH W. (1971). The teratogenic action of ethylurea and nitrite in rats. *Experientia* 27(5), 538–539.

AL-AWADI, S. A., FARAG, T. I., TEEBI, A. S., NAGUIB, K. K., AND EL-KHALIFA, M. Y. (1984). Anencephaly: Disappearing in Kuwait? *Lancet* 2, 701–702.

ANDERSON, L. M., GINER-SOROLLA, A., AND EBELING, D. (1978). Effects of imipramine, nitrite, and dimethyl-nitrosamine on reproduction in mice. *Res. Commun. Chem. Pathol. Pharmacol.* 19, 311–327.

Association of Food and Drug Officials of the United States (1979). *Appraisal of the Safety of Chemicals in Foods, Drugs and Cosmetics.*

BIRDSALL, J. J. (1981). Human dietary nitrite intake and results of animal feeding studies of nitrite. Presented at the Public Meeting of the Committee on Nitrate and Alternative Curing Agents in Food, January 2, 1981, National Academy of Sciences, Washington, D.C.

California Department of Health Services (CDHS) (1977). *California Domestic Water Quality and Monitoring Regulations.* Excerpts from the California Health and Safety Code and the California Administrative Code, Title 22.

CARLSON, D. J., AND SHAPIRO, F. C. (1970). Methemoglobinemia from well water nitrates: A complication of home dialysis. *Ann. Intern. Med.* 73, 757–759.

COFFEY, V. P., AND JESSOP, W. J. E. (1957). A study of 137 cases of anencephaly. *Brit. J. Prevent. Soc. Med.* 11, 174–180.

COMLY, H. H. (1945). Cyanosis in infants caused by nitrates in well water. *J. Amer. Med. Assoc.* 129, 122.

CRAUN, G. F., GREATHOUSE, D. G., AND ZUNDERSON, D. H. (1981). Methemoglobin levels in young children consuming high nitrate well water in the United States. *Int. J. Epidemiol.* 10, 309–317.

DAVIDSON, K. (1964). Nitrate toxicity in dairy heifers. *Dairy Sci.* 47, 1065.

DEEB, B. S., AND SLOAN, K. W. (1975). *Nitrates, Nitrites, and Health.* Bulletin 750, Agricultural Experiment Station, Colleges of Agriculture and Veterinary Medicine, University of Illinois at Urbana, Champaign.

DISKALENKO, A. P. (1968). Methemoglobinemia of water-nitrate origin in the Moldovavian S.S.R. *Hyg. Saint.* 33, 32–37.

DONAHOE, W. E. (1949). Cyanosis in infants with nitrates in drinking water as cause. *Pediatrics* 3, 308–311.

DORSCH, M. M., SCRAGG, R. K. R., MCMICHAEL, A. J., BAGHURST, P. A., *et al.* (1984). Congenital malformations and maternal drinking water supply in rural South Australia: A case–control study. *J. Epidemiol.* 119, 473–485.

DREOSTI, J. E., MCMICHAEL, A. J., AND BRIDLE, T. M. (1983). Teratogenic effect of extended administration of N-nitrosoethylurea and ethylene/nitrite in rats. *Res. Commun. Chem. Pathol. Pharmacol.* 41, 265–281.

ELWOOD, J. M., AND ELWOOD, J. H. (1980). *Epidemiology of Anencephalus and Spina Bifida.* Oxford Univ. Press, New York.

EMERICK, R. J. (1974). Consequences of high nitrate levels in feed and water supplies. *Fed. Proc., Fed. Amer. Soc. Exp. Biol.* 33, 1183–1187.

Food and Drug Administration (FDA) (1972a). *GRAS (Generally Recognized as Safe) Food Ingredients. Nitrates and Nitrites (Including Nitrosamines).* Prepared by the Battelle Columbus Laboratories for the U.S. Food and Drug administration, Washington, D.C. NTIS PB-221 220.

Food and Drug Administration (FDA) (1972b). *Teratologic Evaluation of FDA 71-7 (Sodium Nitrate).* Prepared by the Food and Drug Research Labs., Inc., for the Food and Drug Administration, Washington, D.C. NTIS PB-221 775.

Food and Drug Administration (FDA) (1972c). *Teratologic Evaluation of FDA 71-8 (Potassium Nitrate).* Prepared by the Food and Drug Administration, Washington, D.C. NTIS PB-221 774.

FRASER, P., AND CHILVERS, C. (1981). Health aspects of nitrate in drinking water. *Sci. Total Environ.* 18, 103–116.

GLOBUS, M., AND SAMUEL, D. (1978). Effect of maternally administered sodium nitrite on hepatic erythropoiesis in fetal CD-1 mice. *Teratology* 18, 367–378.

GOSSELIN, R. E., SMITH, R. P., AND HODGE, H. C. (1984). *Clinical Toxicology of Commercial Products,* pp. III-123 to III-130. Williams & Wilkins, Baltimore.

GREEN, L. D., TENNEBAUM, S. R., AND FOX, J. G. (1982). Nitrate in human and canine milk. *N. Engl. J. Med.* 306, 1367–1368.

GRUENER, N., AND SHUVAL, H. I. (1970). Health aspects of nitrates in drinking water. In *Developments in Water Quality Research.* Ann Arbor–Humphrey Science Pub., Ann Arbor, MI/London.

GRUENER, N., AND SHUVAL, H. I. (1973). Methemoglobinemia induced by transplacental passage of nitrites in rats. *Bull. Environ. Contam. Toxicol.* 9, 44–48.

HARTMAN, P. E. (1982). Nitrates and nitrites: Ingestion, pharmacodynamics, and toxicology. *Chem. Mutagen.* 7, 211–294.

HEINZ, R., HORING, H., ELLINGER, C., BUSCHMANN, J., AND CLASSING, P. (1983). On the prenatal toxic effect of oral administration of nitrate to rats. *Z. Ges. Hyg.* 29, 667–669.

INUI, N., NISHI, Y., TAKETOMI, M., AND MORI, M. (1979a). Transplacental action of sodium nitrate on embryonic cells of Syrian golden hamster. *Mutat. Res.* 66, 149–158.

INUI, N., NISHI, Y., TAKETOMI, M., MORI, M., YAMAMOTO, M., TAKASHI, Y., AND TANIMURA, A. (1979b). Transplacental mutagenesis of products formed in the stomach of golden hamsters given sodium nitrite and morpholine. *Int. J. Cancer* **24**, 365–372.

JONES, J. H., SETHNEY, H. T., SCHOENHALS, G. W., GRANTHAM, R. N., AND RILEY, H. D. (1973). Grandmother's poisoned well: Report of a case of methemoglobinemia in an infant in Oklahoma. *Oklahoma State Med. Assoc. J.* **66**, 60–66.

KESHAVIAH, P., AND LUEHMANN, D. A. (1981). Overviews of the FDA contract report: Investigation of the risk and hazards with hemodialysis devices. In *Investigation of the Risk and Hazards Associated with Hemodialysis Devices*. An FDA Medical Device Standards Publication. Technical Report. U.S. Department of Health, Education, and Welfare, Silver Springs, MD.

KHERA, K. S. (1982). Reduction of teratogenic effects of ethylenethiourea in rats by interaction with sodium nitrite *in vivo*. *Food Chem. Toxicol.* **20**, 273–278.

LACHHEIN, L., THAL, W., AND HARNACK, O. (1960). Methamoglobinamien durch Brunnenwasser bei Sauglingen. *Dtsch. Gesundheitsw.* **15**, 2339–2343.

MAKOTO, E., AND SEIZABURO, K. (1983). Studies on the pharmacological basis of fetal toxicity of drugs. III. Fetal toxicity of potassium nitrite in two generations of rats. *Folia Pharmacol. Japon.* **81**, 409–480.

MALESTEIN, A., GEURINK, J. H., SCHUYT, G., SCHOTMAN, A. J., KEMP, A., AND KLOOSTER, A. T. (1980). Nitrate posioning in cattle. The effect of nitrite dosing during parturition and the oxygen capacity of maternal blood and the oxygen supply to the unborn calf. *Tijdschr. Diergeneeskd.* **105**, suppl. 3, 149–159.

MCKEE, J. E., AND WOLF, H. W. (Eds.) (1963). *Water Quality Criteria*. 2nd ed. State Water Resources Control Board, Sacramento, CA.

MILLER, S. A. (1980). Balancing the risks regarding the use of nitrites in meats. *Food Technol.* **34**. 254–256.

MYRIANTHOPOULOS, N. C. (1979). Recent advances in the developmental biology of central nervous system malformations. *Birth Defects Original Article Series* **15**, 118–129.

National Academy of Sciences (NAS) (1978). *Nitrates: An Environmental Assessment*. National Academy of Sciences, Washington, D.C.

National Academy of Sciences (NAS) (1981). *The Health Effects of Nitrate, Nitrite, and N-Nitroso Compounds*. National Academy of Sciences, Washington, D.C.

SCRAGG, R. R., DORSCH, M. M., MCMICHAEL, A. J., AND BAYHURST, P. A. (1982). Birth defects and household water supply. Epidemiological studies in the Mount Zambia region of South Australia. *Med. J. Austral.* **2**, 577–579.

SEVER, L. E. (1975). Zinc and human development: A review. *Human Ecol.* **3**, 43–57.

SHANK, R. C., AND NEWBERNE, P. M. (1976). Dose-response study of the carcinogenicity of dietary sodium nitrite and morpholine in rats and hamsters. *Food Cosmet. Toxicol.* **14**, 1–8.

SHEARER, L. A., GOLDSMITH, J. R., YOUNG, C., KEARNS, O. A., AND TAMPLIN, B. (1972). Methemoglobin levels in infants in an area with high nitrate water supply. *Amer. J. Public Health* **62**, 1174–1179.

SHUVAL, H. I., AND GRUENER, N. (1971). Epidemiological and toxicological aspects of nitrates and nitrites in the environment. Presented at the 99th Annual Meeting of the American Public Health Association, Minneapolis, MN, October 13, 1971.

SHUVAL, H. I., AND GRUENER, N. (1972). Epidemiological and toxicological aspects of nitrates and nitrites in the environment. *Amer. J. Public Health* **62**, 1045–1052.

SHUVAL, H. I., AND GRUENER, N. (1974). Effects on man and animals of ingesting nitrates and nitrites in water and food. In *Effects of Agricultural Production on Nitrates in Food and Water with Particular Reference to Isotope Studies*. IAEA, Vienna, Austria. STI/PUB361.

SHUVAL, H. I., AND GRUENER, N. (1977). Infant methemoglobinemia and other health effects of nitrates in drinking water. *Prog. Water. Technol.* **8**, 183–193.

SIMON, C. H., MAZKE, M., KAY, H., AND MROWITZ, G. (1964). On the occurrence, pathogenesis, and possibilities for prophylaxis of the methemoglobinemia caused by nitrite. *Z. Kinderheikunde.* **91**, 124–138.

SINHA, O. P., AND SLEIGHT, S. (1971). Pathogenesis of abortion in acute nitrite toxicosis in guinea pigs. *Toxicol. Appl. Pharmacol.* **18**, 340–347.

SLEIGHT, S. D., AND ATALLAH, O. (1968). Reproduction in the guinea pig as affected by chronic administration of potassium nitrate and potassium nitrite. *Toxicol. Appl. Pharmacol.* **12**, 179–185.

SMILKSTEIN, G. (1962). A ten year study of anencephaly. *Calif. Med.* **96**, 350–353.

SMITH, R. P. (1980). Toxic responses of the blood. In *Casarett and Doull's Toxicology: The Basic Science of Poisons* (J. Doull, C. D. Klaassen, and M. O. Amdur, Eds.), 2nd ed., pp. 311–331. Macmillan Co., New York.

SPIEGELHALDER, R., EISENBRAND, G., AND PREUSSMANN, R. (1976). Influence of dietary nitrate on nitrite content of human saliva: Possible relevance to *in vivo* formation of *N*-nitroso compounds. *Food Cosmet. Toxicol.* **14**, 545–548.

STEVENSON, A. C., JOHNSON, H. A., STEWART, M. I. P., AND GOLDING, D. R. (1966). Congenital malformations—A report of a study of a series of consecutive births in 24 centres. *Bull. WHO* **34**, 1–125.

SUBBOTIN, F. N. (1961). Nitrates in drinking water and their effect on the formation of methemoglobin. *Gig. Sanit.* **25**, 13–17.

SUPER, M., DE, V., HESSE, H., MACKENZIE, D., DEMPSTER, W. S., DU PLESSIS, J., AND FERREIRA, J. J. (1981). An epidemiological study of well-water nitrates in a group of South West African/Namibian infants. *Water Res.* **15**, 1265–1270.

TERAMOTO, S., SAITO, R., AND SHIRASU, Y., (1980). Teratogenic effects of combined administration of ethylenethiourea and nitrite in mice. *Teratology* **21**, 71–78.

THE, T. L. (1982). Anencephaly and myeloschisis developed from experimentally produced neural tube tissue overgrowth by treating chick embryos with sodium nitrite. *Anat. Rec.* **202**, 189A–190A.

VIRGIL, J., WARBURTON, S., HAYNES, W. S., AND KAISER, L. R. (1965). Nitrates in municipal water supply cause methemoglobinemia in infant. *Public Health Rep.* **80**, 1119–1121.

VORHEES, C. V., BUTCHER, R. E., BRUNNER, R. L., AND WOOTTEN, V. (1984). Developmental toxicity and psychotoxicity of sodium nitrite in rats. *Food Chem. Toxicol* **22**, 1–6.

WALTON, B. (1951). Survey of the literature relating to infant methemoglobinemia due to nitrate contaminated water. *Amer. J. Public Health* **41**, 986–996.

WHITE, J. W. (1976a). Relative significance of dietary sources of nitrate and nitrite. *J. Agr. Food Chem.* **23**, 886–891.

WHITE, J. W. (1976b). Relative significance of dietary sources of nitrate and nitrite. Correction. *J. Agr. Food Chem.* **24**, 202.

WINTON, E. F., TARDIFF, R. G., AND MCCABE, L. J. (1971). Nitrate in drinking water. *J. Amer. Water Works Assoc.* **63**, 95–98.

World Health Organization (WHO) (1962). Evaluation of the toxicity of a number of antimicrobials and antioxidants. In *Sixth Report of the Joint FAO/WHO Committee on Food Additives*. World Health Organization Technical Report Series No. 228. WHO, Geneva.

World Health Organization (WHO) (1977). *Nitrates, Nitrites and* N-*Nitroso Compounds*. Environmental Health Criteria 5, WHO, Geneva.